A parametric analysis of the thermal properties of contemporary materials used for house construction in South-west Nigeria, using thermal modelling and relevant weather data

Volume 1

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A thesis submitted in accordance with the requirements of the University of Liverpool for the Degree of Doctor of Philosophy (PhD)

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March 2019

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Declaration

I certify that this thesis constitutes my own work/investigation, except where otherwise stated; explicit references acknowledge other sources.

I declare that this thesis describes original work that has not been presented for the award of any other degree of any institution.

Signed: ____________________

Date: 04-10-2018

Abstract

Climate change, its causes and effects have become a topical issue in the world today. Universal increases in temperature and sea levels, are evidences of this global phenomenon. In the field of architecture, climate-resilient and climate-responsive domestic buildings are being developed to adapt to changing climates, while being socio-economically suited to their geographical contexts. Much research in this area has been carried out in developing tropical countries such as Nigeria. Most studies concentrate on passive optimisation of building envelopes to promote thermal comfort and reduce reliance on active mechanical controls which worsen climate change. Thus, it may be said that thermal comfort has been established as a link between climate change and housing. In south-west Nigeria, where an abundance of tropical rainforests engenders a hot-humid climate, achieving thermal comfort in buildings is a major need. Studies show that of all house envelopes in south-west Nigeria through time, two housing styles namely the pre-colonial traditional and colonial modernist styles best demonstrate effective use of climatic design principles in achieving thermally comfortable interiors. However, due to cultural changes over time, a third style of housing which is referred to as contemporary south-west Nigerian housing, is currently the most preferred form of housing. South-west Nigerian contemporary house shows considerable influence from the International Style. This housing style features envelopes with minimum use of climatic design principles and maximum reliance on mechanical cooling devices such as air conditioners, in providing indoor thermal comfort. These mechanical devices, however, are known for aggravating south-west Nigerian climate change. To reduce the aggravation of climate change caused by south-west Nigerian contemporary housing envelopes, this study proposes a free-running contemporary house envelope which promotes thermal comfort in present and future south-west Nigerian climates. As such, the study extensively reviewed climatic design principles and thermal standards applicable in tropical climates as well as material on chronological south-west Nigerian housing developments. The study modelled and evaluated the thermal performance of a free-running, base-case contemporary house envelope in present and future climates, using DesignBuilder's dynamic thermal simulations. South-west Nigerian present and future climatic data used in the simulations, were generated by the climatic data source and calculation software Meteonorm. South-west Nigerian present climatic data was validated by readings from data loggers placed in a real-live contemporary base-case house in the region. The results of this study's simulations confirmed that the free-running, base-case contemporary house envelope does not promote thermal comfort in present climates, hence the current supplementary mechanical thermal controls. Additionally, the results showed that the contemporary envelope would not promote thermal comfort in future south-west Nigerian climates. As such, this study then proceeded to optimise the contemporary house envelope to improve its thermal performance in south-west Nigerian present and future climates. This optimisation involved adjusting the envelope specifications under the following parameters: headroom height, external wall (thermal mass, insulation and thickness), internal ground floor (thermal mass, insulation and thickness), roof (thermal mass, pitch, structure, overhang length, covering), external window (size, type, glazing thickness and type), azimuth angle (building orientation) and ground floor elevation distance. These parameters were based on Szokolay's (2014) climatic design principles. The results showed that optimising the south-west Nigerian contemporary envelope under those parameters improved its thermal performance, enabling it to provide indoor thermal comfort in present and future south-west Nigerian climates. Accordingly, this study's main contribution is the proposal of a free-running climate-responsive south-west Nigerian contemporary house envelope which promotes indoor thermal comfort in present and future climates. It recommends that: 1. without any need for mechanical cooling devices, the specifications of this optimised contemporary house envelope can be used to reform housing design policies in south-west Nigeria, and 2. using the optimised envelope would reduce reliance on mechanical thermal controls and therefore mitigate climate change in the region.

Acknowledgements

I would like to express my sincere and deepest gratitude to my supervisor Professor Steve Sharples for his invaluable support and constant encouragement through the highs and lows of undertaking this PhD. Without his guidance, advice, tremendous knowledge and constructive feedback, I would never have been able to accomplish this. Thank you for everything, Steve. I express my immense gratitude to my friends and colleagues for the extremely useful discussions, advice and encouragement which contributed to my finding much-needed direction at different points in the journey. I am extremely grateful to Arc. Deji Adepeju for his tremendous assistance. I am indeed grateful. In addition, I declare my sincere appreciation to Professor Ola Uduku and Dr Rosa Urbano Gutierrez, for agreeing to examine my thesis, and taking the time to review it. I extend the most earnest, heat-felt gratitude to my parents and brothers for their constant love, unwavering faith in me, priceless support and sacrifice throughout the period of the doctorate program. Daddy, Mummy, Ore, Ola and Akin, I love you all; thank you for everything. Finally, I acknowledge my Creator, the one true, living God, the God of Abraham, Isaac and Jacob, the Father of my Lord Jesus Christ, who has provided me with breath and grace to accomplish this.

Table of Contents

Volume 1

CHAPTER 4: SOUTH-WESTERN NIGERIAN DOMESTIC ENVELOPES AND CLIMATE-RESPONSIVENESS – A HISTORICAL AND SOCIAL PERSPECTIVE

Volume 2

CHAPTER 5: THERMAL EVALUATION AND OPTIMISATION OF THE TRADITIONAL AND CONTEMPORARY SOUTH-WEST NIGERIAN HOUSE ENVELOPES – A STUDY OF THE CLIMATE-RESPONSIVENESS OF DOMESTIC BUILDING ENVELOPES IN PRESENT AND FUTURE CLIMATES [PHASE A]

CHAPTER 6: THERMAL EVALUATION AND OPTIMISATION OF THE TRADITIONAL AND CONTEMPORARY SOUTH-WEST NIGERIAN HOUSE ENVELOPES – A STUDY OF THE CLIMATE-RESPONSIVENESS OF DOMESTIC BUILDING ENVELOPES IN PRESENT AND FUTURE CLIMATES [PHASE B]

List of Figures

List of Sheets

List of Tables

Chapter 1

The Approach – Sustainable Architecture, Climate Change and South-west Nigerian contemporary Housing

"As we evolve, our homes should, too."
Suzanne Tucker, 2013

1.0 Sustainability, Architecture and Climate Change

Sustainability or sustainable development has become a world-renowned concept. According to Scoones (2007, 589), sustainability is "*one of the most widely used buzzwords of the past two decades*." The concept of sustainability represents ethics governing the activities carried out by numerous professions in contemporary times. Sustainability or sustainable development is "…*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Bruntland Commission, 1987). Architecture is one such discipline that is guided by principles of sustainability, in which terms such as 'sustainable design' and 'sustainable buildings' among others, have become popular (Guy & Farmer, 2001). Sustainable housing is a related construct which has become globally relevant in tackling people's basic need for shelter. Sustainable housing represents housing that is cost-effective, eco-friendly and which optimises the living standards of the residents (Tessema, Taipale and Bethge, 2009). In the wake of climate change, there has been increased focus on developing housing that is responsive to present climates without causing further climatic changes.

Climate change research has shown that certain geographical areas are more vulnerable to climate change, one of which is the tropics. In the tropics, climate change seems to aggravate existing problems, such as poverty. Therefore, there is an increasing emphasis on climate change mitigation and adaptation strategies. In the architectural sector, contemporary tropical buildings have been observed to aggravate climate change. Generally, buildings are created within external climates and create internal/indoor climates (Lawal & Ojo, 2011). Climate-responsiveness judges the ability of a building to control its internal climate in relation to external climates. As such, the nature of the building envelope and thermal comfort levels are good indicators of a building's climate-responsiveness (ibid). However, it appears that contemporary tropical building envelopes can only create comfortable indoor thermal environments if augmented with mechanical thermal controls (Kamal, Wahab & Ahmad, 2014; Short, 2017). These controls cool and de-humidify indoor thermal environments – essential requirements because of the extreme nature of tropical climates.

However, these mechanical controls promote global warming, causing increases in temperature and other imbalances to natural systems (Salmon, 1999; Short, 2017). A study of the historical development of architecture in most tropical regions show that earlier building types, such as the traditional/indigenous and colonial types, were able to create comfortable interiors without reliance on mechanical controls (Denyer, 1978; Dmochowski, 1990; Karol & Chin Lai, 2014; Short, 2017). It has been observed that these earlier types were designed using climatic design principles which seem lacking in tropical contemporary building design. The traditional types show autonomous/spontaneous responses to climate while colonial types show planned responses; these responses are regarded as passive thermal controls implemented in the building envelope (Shaw, Colley & Connell, 2007; Szokolay, 2014). However, contemporary buildings also show planned climatic responses predominantly through active thermal (mechanical controls) which foster climate change (Ibid; Ibid; Short, 2017). Therefore, many researchers are stipulating that building designers return to the implementation of climatic design principles for tropical contemporary building design (Prianto et al, 2000; SEAV, 2002; Short, 2017). It is stated that this would reduce reliance on mechanical controls and thus, represent an effort at climate change mitigation and adaptation in the most vulnerable tropical regions. This study keys into this climate adaptation and mitigation trend by developing climate-responsive contemporary housing in tropical south-west Nigeria.

1.1 Thermal comfort and the building envelope – the link between climate change and housing

Recent studies on climate change and housing suggest a strong emphasis on thermal comfort. Indeed, it may be said that thermal comfort is the link between climate and housing (Lawal & Ojo, 2011). The building envelope or fabric may be referred to as a catalyst in this relationship (Salmon, 1999). Its basic components are the roof, walls, and floor (ASHRAE, 2009). Considering its relevance in this context, the building envelope appears ambivalent in function, contributing to climate change and at the same time regulating indoor climates (Latha, Darshana & Venugopal, 2015). The implementation of climatic design principles determines how effective the building envelope is at controlling the amount of heat lost or gained across the envelope in tropical climates (Butera, Adhikari & Aste, 2014). In this regard, research has revealed that the typical contemporary tropical building envelope features minimum application of passive climatic design. An example of non-application of climatic design principles in the contemporary tropical envelope is the use of materials which are ill-suited to the tropical climate's thermal problems. Consequently, the envelope needs to be supplemented with thermal control systems such as air conditioning units (Tessema, Taipale & Bethge, 2009). Air conditioning units are however known for generating gaseous waste which accumulates in the atmosphere and fosters climate change (Thiele, 2013). Additional gases are emitted during the production of contemporary building materials such as glass and steel, further contributing to climate change (Ibid). Consequently, there is an ongoing advocacy for designing tropical contemporary, domestic building envelopes with materials that are climate-responsive (environment-friendly and promote thermal comfort). Such climate-responsive materials are used in traditional construction. An endorsement of total reliance on climate-responsive materials has led to the concept of contemporary free-running envelopes. Free-running envelopes are devoid of any thermal control systems (de Dear & Brager, 1998; Hensen & Centnerova, 2001; Short, 2017). In addition to the use of climate-responsive materials, studies recommend the use of other passive design principles in developing free-running contemporary tropical envelopes. Therefore, researches in this field are advocating the development of climate-responsive contemporary envelopes, by learning from the way traditional and colonial envelopes demonstrate climatic design (Tessema, Taipale & Bethge, 2009). Studies have shown that indigenous houses are rated by their occupants as more thermally comfortable than contemporary equivalents (Ogunrin, 2014; Adunola, 2014). Thus, research trends involve assessing and comparing thermal comfort in traditional and contemporary house types in tropical regions (O'Brien, 2006; Cheng, Ng & Givoni, 2005). Operative temperatures within the indoor spaces of both types of houses, are evaluated against applicable thermal comfort standards (Nowak, Nowak-Dzieszko, & Rojewska-Warchal, 2013).

Furthermore, research findings indicate that not only do indigenous materials indeed possess desirable thermal properties, they are enhanced by affordability as opposed to contemporary materials (Tessema, Taipale & Bethge, 2009). Affordability is an issue tied to current concerns about climate change in tropical regions due to its negative implications for local economies. As a result, usage of affordable, eco-friendly and climate-responsive building materials is constantly recommended as a strategy for adapting housing to tropical climate change (Thiele, 2013). However, it seems that the general use of climatic design gives traditional envelopes a thermal edge over contemporary envelopes in the tropics (Tessema, Taipale & Bethge, 2009). Although climatic design has been proven to foster thermal comfort in past and present climates, it seems that there is very little knowledge about the viability of climatic design in future tropical climates (Ibid). Accordingly, this study explores the relationship between thermal comfort and the application of climatic design principles in the building envelope, with regards to climate change and the socio-economic context of south-west Nigeria.

1.2 South-west Nigeria: Where the Yoruba call 'Home'

The tropical region of south-west Nigeria has been home to the Yoruba for centuries (Laitin, 1986). The population of the region has been estimated at 32.5 million people and they account for about 21% of Nigeria's total population (Action on Armed Violence (AOAV), 2014). Among hills and grassland, thick forests and water falls, this tropical region has accommodated a people who started off living a simple agrarian culture (Osasona, 2007a). However, colonialism introduced access to more sophisticated living deriving from economic and infrastructural development. Erstwhile farmers gained access to western education and lifestyles. Currently, ancient Yoruba towns have greatly expanded, and mud houses have been replaced with contemporary concrete, glass and steel cuboidal dwellings showing influences from the Western International Style architecture (Prucnal-Ogunsote, 1993). After independence from colonial rule, there was a creation of innovative tropical styles (Public Works Department (PWD) and tropical modernism) in south-west Nigerian cities, especially among public buildings (Fry & Drew, 1964). Yoruba housing generally shows less dramatic chronological transformations when compared with public buildings (due to the preservation of the original Yoruba family structure). However, one thing is evident: the socio-economic stratification in south-west Nigerian housing, as explained in the following sections.

The general notion in contemporary south-west Nigerian society is that the original indigenous mud family houses and colonial cement houses are for the low-income bracket (Fourchard, 2003). By contrast, the contemporary concrete/sandcrete-walled, aluminium-roofed one-storey house with glass sliding windows on a self-contained plot of land is associated with the middle classes. This latter type of housing is readily perceived as the desirable standard family house (Okeyinka & Amole, 2012). According to Rodas, Molini & Oseni (2017), middle-income Nigerians earn about ₦2,707,500 (£5898.56) annually. Adewunmi (2011) provides more information on this class. A survey of 1,004 middle-class Nigerians revealed some 92% of this socio-economic class had post-secondary school education and 99% had at least one family member involved in full- or part-time work. Furthermore, over 50% were skilled professionals in paid employment, 38% entrepreneurs and 2% were involved in other types of work. Adewunmi's (2011) study indicates that these middle-class earners place a great deal of importance on giving their children access to good education and enlightened cultures. Of more importance to this study is the common aspiration among the middle-income earners to acquire the contemporary house-type as a symbol of socio-economic accomplishment.

On the downside however, studies show that the building envelope of contemporary south-west Nigerian housing seems to contribute to climate change and thermal discomfort (Osasona, 2007a; Immerwahr, 2007; Jiboye et al, 2010; Adunola, 2014; Olaniyan, Ayinla & Odetoye, 2015). Use of electricity generating sets commonly called generators, is almost a constant feature of this house-type. These generators are installed to power the air conditioners and fans used for cooling indoor domestic spaces (Ezema, Opoko & Oluwatayo, 2016). They are known for releasing greenhouse gases into the atmosphere (Rural Women Energy Security Project (RUWES), 2015). Furthermore, air conditioning units which aggravate climate change, tend to be a constant feature in south-west Nigerian contemporary house envelopes (Ibid) (see Figure 1.1). Accordingly, studies continue to emphasise borrowing from the Yoruba traditional family

Figure 1.1 A south-west Nigerian contemporary residential envelope with installed air conditioning unit; source: author's study.

house architecture. The traditional building envelope is free-running and made of locally-sourced, eco-friendly materials (Jiboye & Ogunshakin, 2010). Furthermore, as the traditional envelope was created by people without formal architectural training, it is reported to demonstrate autonomous or spontaneous adaptation and responses to the climate. Several studies have compared thermal comfort and climate-responsiveness of Yoruba traditional building envelopes with the same attributes in contemporary building envelopes (Lawal & Ojo, 2011; Olaniyan, Ayinla & Odetoye, 2013; Adunola, 2014). Many of these studies assess the contributions of contemporary house envelopes to climate change and describe the construction as unsustainable. So far, it seems that these studies have duly identified the problems and proferred solutions. However, very few have investigated the feasibility and effectiveness of the proposed solutions for improving contemporary building envelopes. Furthermore, existing studies consider only present south-west Nigerian climates; climate change in future years seems to be overlooked. Therefore, this study focuses on developing a contemporary house envelope that yields optimum thermal comfort in present and future climates. It does so by investigating climate-responsive features across all house-types (past and present). As such this study improves the contemporary envelope with the application of climatic design principles, while learning from the traditional envelope which shows some of these principles.

1.3 The Research Process

1.3.1 Research Question, Objectives and Study Design

With the existing gap in knowledge identified above, this study aims to answer the major question:

> **Is it possible to create a free-running, climate-responsive contemporary domestic building envelope which promotes optimum indoor thermal comfort in present and future south-west Nigerian climates?**

To answer the main question, the following objectives will be met:

1. To determine what constitutes traditional and contemporary housing in south-west Nigeria.
2. To investigate the nature of south-west Nigerian climate change and its relationship with housing.
3. To determine the climate-responsiveness and ability of traditional and contemporary south-west Nigerian house envelopes to provide optimum thermal comfort in present and future climates.
4. To ascertain which envelope provides better thermal comfort overall in present and future climates between the traditional and contemporary family house envelopes.
5. To determine what design principles (within the context of climate responsiveness and adaptation in residential building envelope design) apply in the south-west Nigerian context.
6. To develop a climate-resilient and adaptive contemporary south-west Nigerian house envelope, that will promote optimum thermal comfort now and in the future.
7. To ascertain if there are construction features of the traditional family house envelope that can be borrowed and infused into this optimally performing contemporary building envelope.
8. To establish if the combination of planned and autonomous climate adaptation is applicable in developing a climate-resilient and adaptive SW Nigerian contemporary house envelope template, which would promote optimum thermal comfort now and in the future.

Accordingly, the study design is retrospective-prospective (Kumar, 2011) (see Figure 1.2). The study relies heavily on pre-existing (secondary) data. These data pertain to past and present housing trends, climate change, climatic design and thermal comfort in the tropics. This stream of secondary data includes information on south-west Nigerian chronological housing trends, which is garnered to examine the development of housing in the region. On the other hand, primary data that is specifically generated for this study, comprises data on present and future thermal comfort in the concerned house-types as well as present and future south-west Nigerian climatic information.

1.3.2 Research Scope

This study is limited in scope to the following:

- Primary focus on the building envelopes of the most common traditional and contemporary house-types in south-west Nigeria.
- The south-western Nigerian context, although the proposed building envelope could be used in similar socio-cultural and climatic environments.
- A duration of thirty years (from the present) is set as the timeframe within which the proposed building envelope should remain suitable to prevailing climates.
- Assessing the traditional, base-case contemporary, and proposed contemporary building envelope based on the parameters of thermal performance and climate-responsiveness.
- Proposing a template for a middle-income contemporary, climate-responsive domestic building envelope suitable for use by the typical middle-income south-western Nigerian family.

1.3.3 Research Methods and Methodology

Kothari (2004) highlights the difference between *research methods* and *research methodology.* While research methods are the techniques that the researcher uses in carrying out the research, research methodology refers to the logic behind chosen research methods or techniques. As such the methodology changes from study to study.

- **Methodology**

Kumar (2014) explains that research can be categorised in terms of application, objectives, and enquiry mode. The application perspective lists two types of research: pure and applied. Pure research entails the development of research methods used in understanding certain phenomena. Differently, applied research involves the collection of information about a certain phenomenon using already-existing research methods, to produce new policies and principles governing that phenomenon (Kumar, 2011). Thus, this study is applied as it investigates the relationship between the building envelope and thermal comfort, with the intentions of proposing improvements in this regard. From the objectives dimension, this

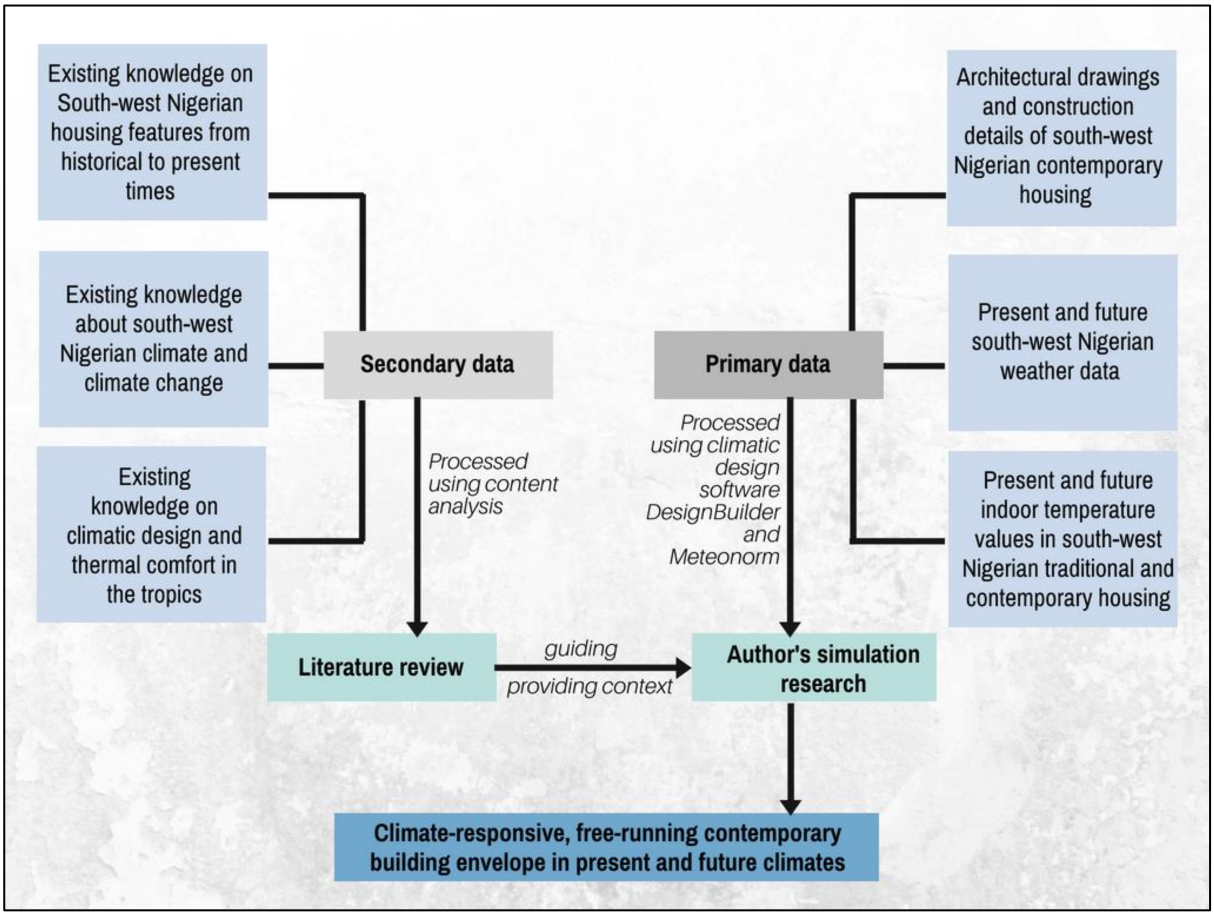


Figure 1.2 Retrospective study design; source: author's study.

study is exploratory, combining descriptive, correlational, and explanatory processes to derive answers (Groat & Wang, 2013). It explores the relationship between the building envelope and thermal comfort considering climate change. The study describes the basics of this relationship. It likewise explains and establishes the necessary relationships between variables and factors. As such, the larger concepts of this study are tropical housing and climate. The chosen indicator of housing is the building envelope and that of climate is indoor thermal comfort. The variables of the building envelope indicator are the different parts such as walls, floors, roof and so on, while that of thermal comfort is operative temperature.

Based on Kumar's (2014) further analyses on the nature of variables, the concepts and variables of this study exhibit certain expetected relationships as depicted in Figure 1.3 below. The independent variable is the building envelope and it comprises changes in any of these four components (parameters) namely: wall, window, roof and floor. In turn, the dependent variable is thermal comfort which is represented by one of its components: the operative temperature. Changes in any of the four components of the building envelope (the independent variable) alter thermal comfort and hence, operative temperature and indoor climate. The external climate, socio-cultural and economic settings are the extraneous variables, which operate in the real-life situation and affects the overall nature of the relationship between the independent and dependent variables. As the external climate is tropical, it follows that tropical standards be used to judge the relationship between the building envelope parameters and the operative temperature. Furthermore, in this milieu, thermal properties of the building envelope parameters may be referred to as the intervening variable. This is because changes in the thermal properties of the independent variable's (the building envelope) components, results in changes in the dependent variable (thermal comfort).

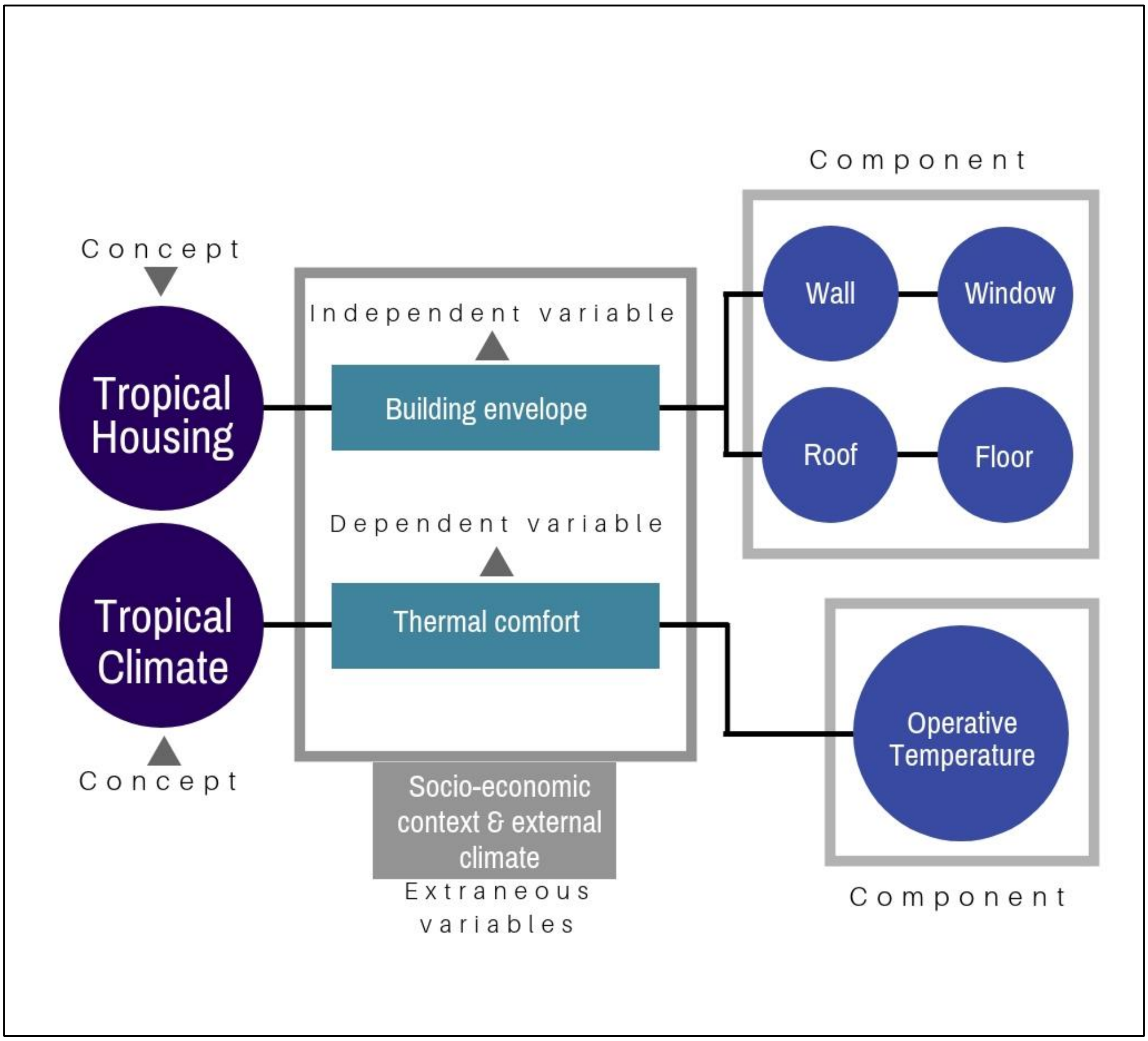


Figure 1.3 Conceptual design; source: author's study.

Additionally, the mode of enquiry perspective classifies this study as using the mixed methods approach, which constitutes the use of qualitative and quantitative methods (see Figure 1.4). This approach seems a logical guide for the study's research methods, as it combines the strengths of qualitative and quantitative methods. As this study examines nuanced, empirically-evaluated socio-cultural concepts as well as rationally-studied physical concepts, its methods are mixed. Furthermore, Lucas (2016) states that studies can be context, methodology or theory-led. Context-led research tailors the nature of the study to the needs of the concerned physical, social or historical setting (Ibid). As this study is situated in the socio-cultural and -economic environs of south-west Nigeria, it is context-led. Therefore, housing in the socio-cultural and economic background of the region, data on its external present and future climates and the corresponding indoor climates of the concerned house-types are required. House typologies are classified on a nominal scale (shared characteristics); socio-economic status has been selected from an ordinal scale with the title of chosen class reflecting income levels (common features resulting in a ranked sub-group) (Kumar, 2014). Additionally, the operative temperature (indicative of thermal comfort) is classified on an interval scale (ºC) (Ibid). As the main question is answered by meeting the research objectives, Figure 1.4 shows which of the two research methods are used per objective.

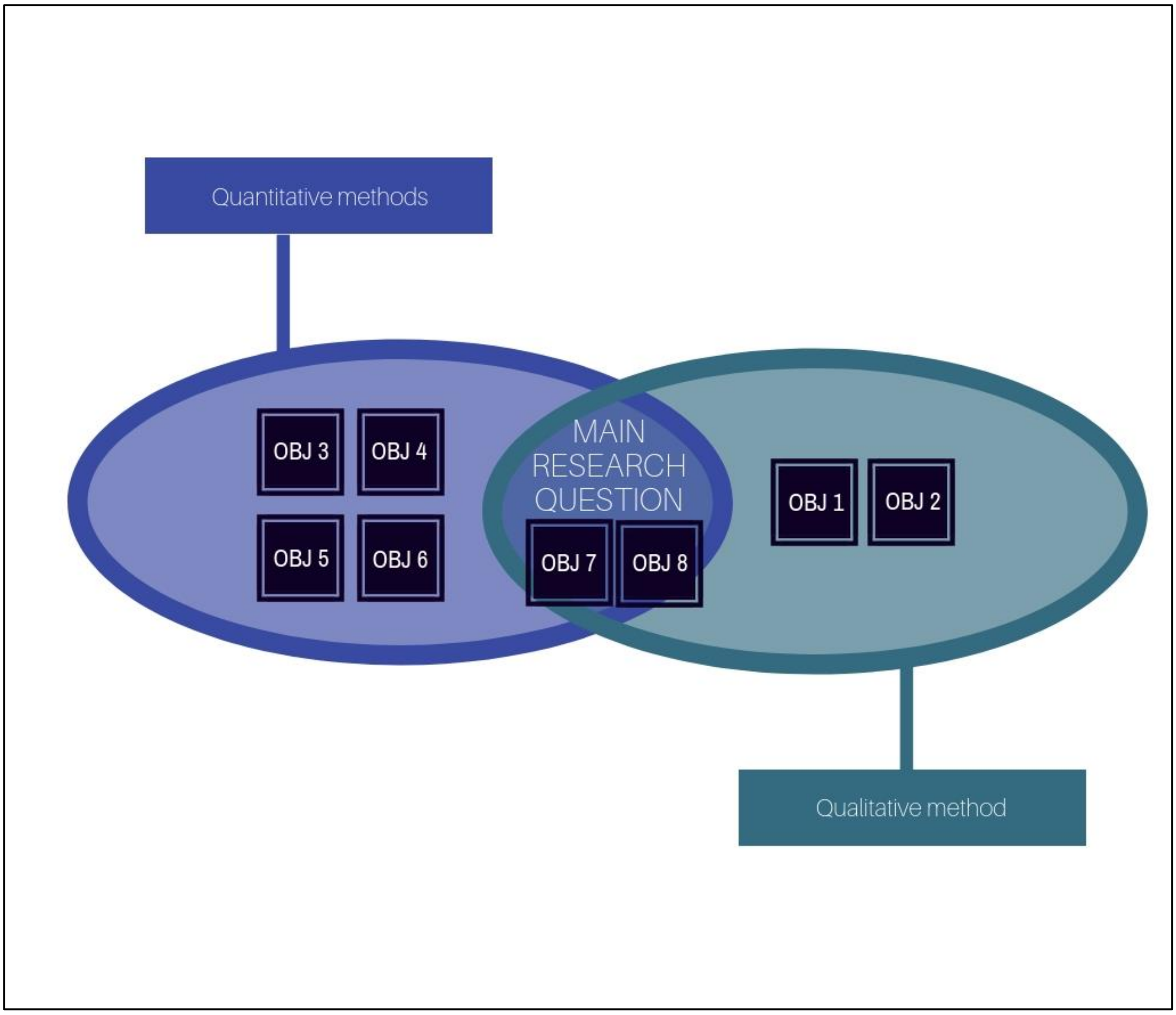


Figure 1.4 Relationship between research methods and objectives; source: author's study.

- **Methods**

1. Quantitative Methods

Lucas (2016) explains that quantitative research involves the objective study of measurable concepts. This type of research aims to establish accurate and undeniable facts about a concept or phenomenon. Accordingly, this study may be said to fall under the big umbrella of building performance studies (Andarini, 2014). This is because it measures the climate-responsiveness of the building envelope by evaluating thermal comfort, indicated by the measurable quantity: temperature. The temperatures derived in the different house-types constitute part of the study's primary data. As such, a quantitative method is used for this purpose. Common quantitative methods used in assessing the thermal comfort-building envelope relationships include field surveys and computer simulation (Szokolay, 1980; Nowak, Nowak-Dzieszko, & Rojewska-Warchal, 2013; Adunola, 2014). This study uses the computer simulation method and the next section describes this method.

Method 1 - Simulation Research

Groat & Wang (2013, p.350) define simulation as being: "…*the representation of the behavior or characteristics of one system through the use of another system, especially a computer program designed for the purpose*...". Simulation occurs when 2D or 3D representations are used to provide measurable information from dynamic relationships under different scenario inputs (ibid). Furthermore, simulation is a representation technique which is very vital to architectural academia and practice (ibid). Groat & Wang (2013, pp.356-357) further assert that in architecture, representation "…*denotes a fixed image that stands for a real object because the image has measurable qualities that describe and depict the real thing*…". Consequently, it may be said that simulation research is a quantitative method. According to Völker et al, (1996), buildings have become much more complex and require equally sophisticated approaches to understanding them. Olaniyan, Ayinla & Odetoye (2013) note that computer simulation has been verified as a viable tool in analysing a building's thermal performance, which is a facet of multi-dimensional building performance. Building simulation is undertaken using models. Groat & Wang (2013, p.357) explain that "…*a model is the overall system that simulates the reality being studied*..." Thus, a model could be iconic, analogue, operational or mathematical. Iconic and analog models are more applicable in building simulation as they deal with physical contexts directly. It is beneficial to back up simulation research with qualitative research because the latter makes the former more meaningful (ibid). As it is useful for testing theoretical preconceptions, this study uses simulation research to test the applicability of contemporary principles on the climate-responsive tropical building envelope in the context of south-west Nigeria.

Simulation research possesses some limitations, but every limitation has a remedy. Groat & Wang (2013) provide a breakdown of these limitations and accompanying solutions. Firstly, simulations might not accurately replicate the live scenario. Fortunately, this limitation is remedied by using the actual objects and materials in the same scale (proportions, specifications, and dimensions) as they would exist in the real world. Simulation technology is always reliant on the input data. However, every single detail of the real world cannot be simulated; this results in incomplete simulated data. Consequently, it is difficult to test the accuracy of the behaviour patterns in computer simulation. Ensuring extensive and complete collection of field data tackles this limitation and ensures the accuracy of the simulated data. The third limitation is that simulated data are not spontaneous and current. However, there is computer technology that can merge various regularly-updated databases into one model, updating simulations based on current information. Furthermore, data derived from simulation, must be properly understood and interpreted. Fortunately, many simulation software export file versions which can be accepted and analysed by statistical analysis software (Olaniyan, Ayinla & Odetoye, 2013). Finally, simulation research can be expensive due to equipment costs and so on. Still, there are various categories of simulation frameworks which have been created/adapted to suit budgets characterising different purposes, whether in academia or practice.

Method 2 - Parametric optimisation

Parametric tools have become very prominent in architectural education and practice due to their potential to improve the quality of design solutions (Hanna, 2012). Parametrics and simulation usually go together, resulting in parametric modelling, where 3D models of buildings are created based on installed parameters (Ibid). As noted by Hanna (2012, p.40), "…*The data that is fed into these parameters is volatile and changeable, and thus, if a designer changes the values inside the parameters, the form of a geometrical entity changes…*". Hanna (2012) further explains that there are two types of parametric modelling (PM): through programs such as Grasshopper in Rhiniceros and, secondly, through programs based on building information modelling (BIM) such as AutoDesk Revit and DesignBuilder (Douglass, 2010). The first type of PM has the advantage of being able to deal with complex geometry while the second type may be referred to as 'traditional': using CAD tools mainly for three-dimensional visualisation, modelling and automation. Nevertheless, both are highly useful for fabrication, façade patterns articulation and design as well structural and environmental optimisation (ibid). According to Butera, Adhikari & Aste (2014), optimisation should be carried out with appropriate quantitative tools. Butera, Adhikari & Aste (2014) add that in the optimisation of building's thermal performance, a viable quantitative tool should consider the building's

- thermal characteristics,
- heating installations and hot water supply including insulation features,
- air conditioning installations
- natural and mechanical ventilation which may include air-tightness
- built-in lighting installation
- the design and orientation of the building, including outdoor climate
- passive solar systems and protection
- indoor climatic conditions, and designed indoor climates, and
- internal loads.

The above list may be said to constitute the parameters affecting simulation outputs. Furthermore, Fross et al (2015) imply that architects should integrate optimisation in their design processes to produce design solutions which anticipate future changes. Accordingly, this study focuses on the study of traditional cuboidal housing forms, and the parametric modelling tool it uses for simulation and optimisation is the BIM-based DesignBuilder.

DesignBuilder in Simulation Research and Parametric Optimisation

DesignBuilder is a building simulation software, which has been uniquely developed to run EnergyPlus simulations on virtual building models (Olaniyan, Ayinla & Odetoye, 2013). EnergyPlus is the U.S. Department of Energy's building energy simulation program for modelling building heating, cooling, ventilation and other energy performance (DesignBuilder, 2009). DesignBuilder is currently a very popular software used in thermal comfort-building envelope studies. It considers all the parameters (listed in preceding discussions) which a robust quantitative tool ought to consider. Olaniyan, Ayinla & Odetoye (2013) used DesignBuilder to assess the thermal comfort in a one-storey model with an area of 13.5m^2 by 10.5m^2. They specified the sandcrete walls, asbestos roofing and ceiling sheets and timber-framed, clear glass louvred windows based on the software's material library provision. Furthermore, they adjusted occupancy periods and ventilation settings to suit the nature of their project. The simulation outputs included solar gains which revealed the inadequate parts of the building envelope under study. Andarini (2014) similarly DesignBuilder thermal simulations of office buildings in Jakarta. The results revealed that building envelope optimisation, combined with presence of high-efficiency equipment and HVAC systems reduced annual energy consumption by 43% in new office buildings. Another instance of DesignBuilder usage is Nowak, Nowak-Dzieszko & Rojewska-Warchal (2013) likewise utilised DesignBuilder to conduct simulations of a commercial building to ascertain thermal comfort of individual rooms. Their study features optimisation of the building envelope by reducing occupancy density and adding internal shading. They used the number of discomfort hours as an indication of the thermal comfort achieved in the model. These studies and countless others highlight the validity and suitability of DesignBuilder software, especially with regards to building performance studies.

EnergyPlus fabric and glazing data are provided through the DesignBuilder software (DesignBuilder, 2009). Therefore, various catalogues of building materials and construction are provided in the DesignBuilder specification libraries. However, the software accommodates models with minimal detail as opposed to more sophisticated CAD and 3D models created for traditional architectural schemes. Therefore, the software simplifies CAD models to process the individual components of the fabric assemblies (Ibid; Wasilowski & Reinhart, 2009). Therefore, it generates models which are abstract in comparison with the realistically rendered CAD models (see Figure 1.5). These models are generated in simulated environments which can be varied under the model data tabs. The DesignBuilder 2009 manual explains all the simulation settings which these model data tabs control. The simulation settings affect data for the site and data for the building model.

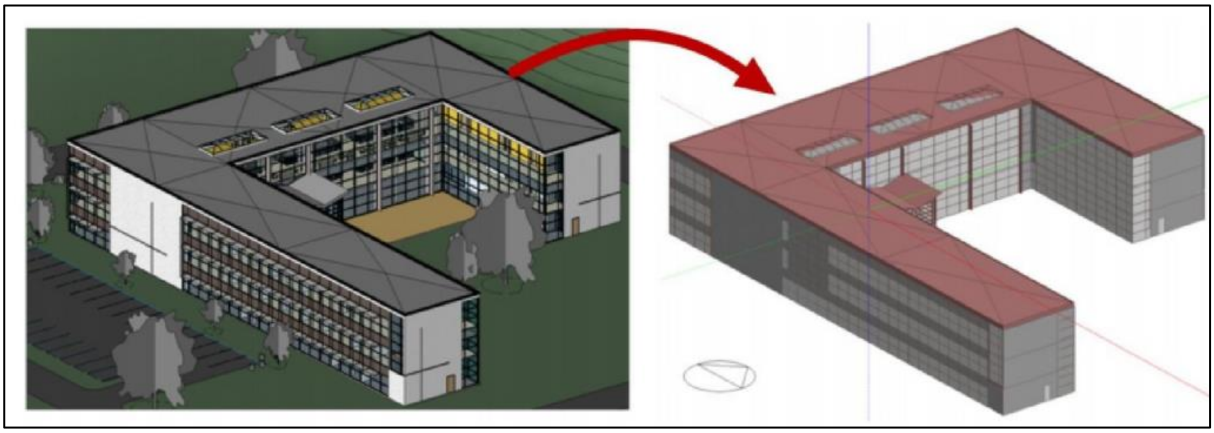


Figure 1.5 A realistic Revit 3D model being abstracted in DesignBuilder; source: DesignBuilder (2018).

Inputting Data into DesignBuilder

1. Model Data for the site

Model data for the site can be inputted and edited at the site level. It is controlled under the location and region tabs (see Figure 1.6). Under the location tab, site location (country, major city), weather data, daylight savings and energy codes may be specified appropriately. Under location, the following details of the site can be set:

- Latitude and longitude,
- Elevation above sea level,
- Site orientation,
- Exposure to wind,

- Ground construction, texture, surface, temperature,
- Precipitation.

Additionally, weather data can be reviewed, edited and converted and hourly weather data can be added under this tab. DesignBuilder uses EnergyPlus .epw format hourly weather data for all its simulations. The user can select the risk percentage that more extreme weather conditions will occur, under for summer and winter design headers. These settings will ensure that more extreme weather phenomena, are considered during the simulations. The Legislative Region and Insulation standards data can be selected under the Region tab. Legislative Region data specifies the energy codes and building regulations implemented in the region. The Insulation Standards header allows the user to determine the energy codes and insulation levels which would inform the outputs of the simulation calculations.

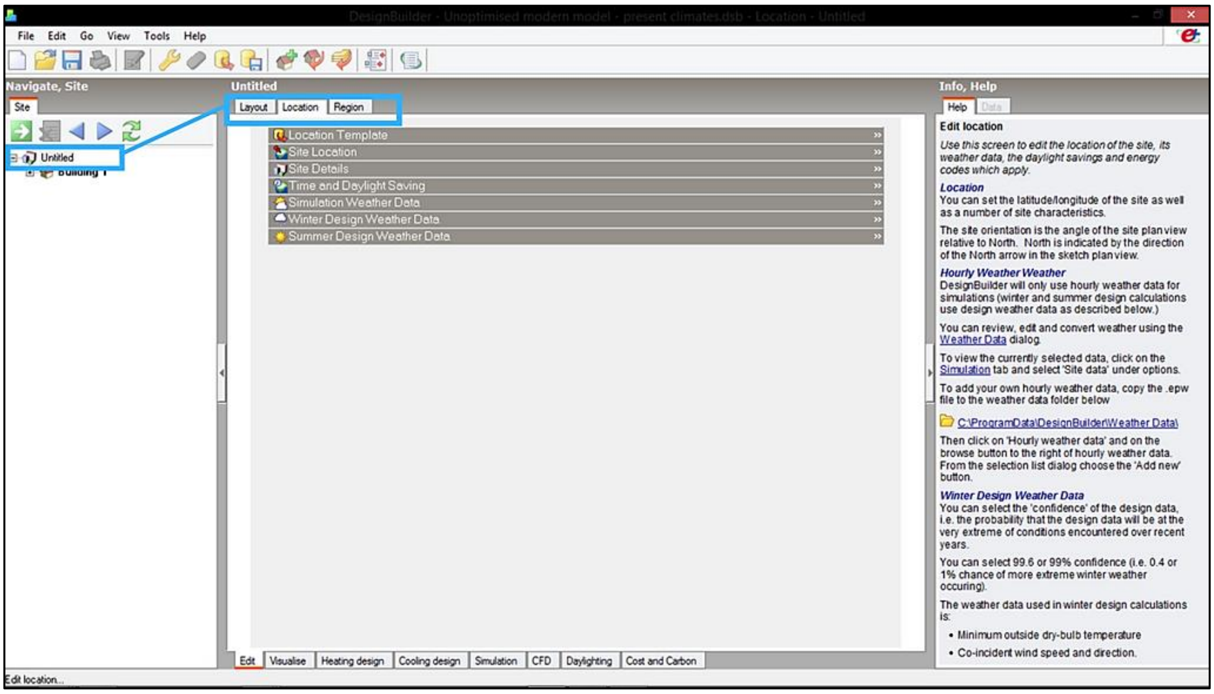


Figure 1.6 DesignBuilder interface showing site model data tabs; source: DesignBuilder (2015).

2. Model Data for the building

The building model data can be inputted and edited at the following levels: block (parts of the superstructure); zone (interior spaces); and surface (construction details). The data is organised under the following tabs:

- **Activity**: The activity tab allows for input or editing of data pertaining to use of interior spaces. It includes information on zone type and addition; occupancy; metabolic rates; domestic hot water (DHW); environmental settings; gains through computer; office equipment; catering; process; and miscellaneous. The zone defines the type of the space which could be occupied or unoccupied, heated and cooled or not, a cavity or a plenum. The occupancy data stipulates the number of building occupants as well as the time of occupancy; it affects the simulation results. The operation schedule ensures that the software considers the effects of typical space usage for each space, in its simulations. The metabolic data controls the total amount of convective, radiant and latent heat gain per person in each zone under design settings. This value changes during simulations according to a correlation which accounts for changes in space temperature. The metabolic data is controlled by an internal algorithm. Through the environmental controls, the user can set heating, cooling, humidity, natural and mechanical ventilation setpoint temperatures, fresh air flow per person and illuminance. The set point temperatures control at what temperature the software would activate heating, cooling, humidification, dehumidification, natural and mechanical ventilation. Target illuminance values are inputted based on the activity within each zone or space. DesignBuilder considers the effect of hot water consumption on building energy use. Under the Activity tab, only the calculated consumption rate of domestic hot water based on the number of occupants and space usage, is displayed. Therefore, DHW use can be included in the model by switching on the DHW under the HVAC tab. Additionally, the software considers heat gains through catering activities, the use of computers, office equipment, and other miscellaneous equipment such as domestic appliances, as well as through processes such as industrial production processes. These gains may be included in the model by switching on the corresponding tabs.

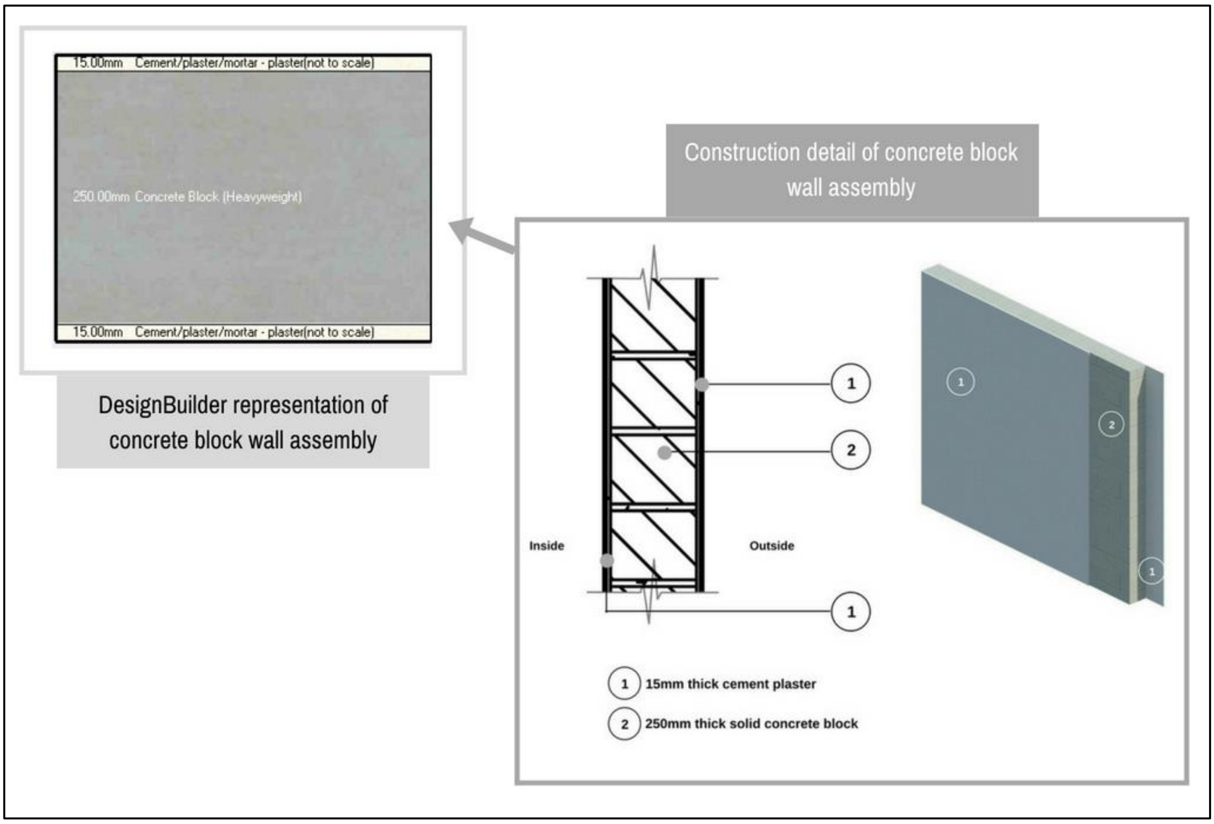


Figure 1.7 DesignBuilder's representation of envelope assemblies; source: DesignBuilder (2015) and author's study.

- **Construction**: Under the construction tab, the user can set the Construction template as either 'Pre-Design' or 'General'. Pre-design construction will limit the user to construction details that are largely created by the software, by adjusting insulation and thermal mass data. However, selecting the 'General' template enables the user to choose from the list of assemblies in the library and provides freedom to create custom assemblies and construction details. Through the construction tab, the user can select construction components of walls, roofs, floors, ground surfaces and other opaque parts of the building fabric. Each component or assembly is modelled in layers, where each layer is a material with editable dimensions (see Figure 1.7). DesignBuilder uses these components to simulate the conduction heat flow through the building fabric. Accordingly, the thermal characteristics of these constructions are processed to generate the thermal properties (heat capacities, U-values and so on) of the fabric parts. Through the construction tab, data on airtightness may likewise be set. To determine air tightness, first the infiltration is switched on or off under the airtightness header. When switched on, the building is modelled as non-airtight and the infiltration rate (in air changes per hour) can be set under the air tightness header.

- **Openings**: The opening tab is used to include windows, doors, vents, holes and sub-surfaces in the main building fabric. To insert openings in the envelope, a template must be set. For example, to include windows in the fabric, a glazing template should be set under the openings tab. Furthermore, the type of opening in relation to the façade can be determined by choosing the appropriate façade type. Data can be inputted on the external and internal window dimensions, frame and glazing type, shading features and control, and mode of operation. The opening of the windows depends on the natural ventilation model under the Activity and HVAC tabs, and the percentage glazing openable area. According to the DesignBuilder (2009, p.218) manual, "…*The % Glazing area opens slider allows you to define the openable window area as a percentage of the total window area. For example, enter '20' if 20% of the window area can open*…" Additionally, the manual (Ibid, p.219) states that "…*The ventilation rate is calculated based on the pressure difference across the opening calculated from wind and stack pressure effects using equations described in Natural Ventilation Modelling…"* Similarly, doors, vents and holes can be added to the fabric. Their placement and operation can be edited under the openings tab accordingly. For holes and vents, the operation may be set as 'closed' or 'control by schedule'. If the control by schedule option is selected, the hole or vent operates according to the natural ventilation settings under the HVAC tab.

- **Lighting**: Simulation settings for lighting can be controlled under the lighting tab. The ouputs of these settings are facilitated by EnergyPlus algorithms. To include lighting features in the model, a lighting template is set so that data from the selected template can be loaded into the model. The type of lighting can be edited by selecting the luminaire type (lighting fixture type) which could be suspended, surface mount, recessed and so on. When lighting is included in the model, lighting heat gains are processed as the software calculates the maximum electrical power required for lighting a zone. The lighted zone may be set appropriately under the lighting areas header. Data can be entered to establish the lighted perimeter area, as well as the fraction of the area receiving artificial and natural light. Additionally, the influence of glare in the model can be simulated by inputting the required data in the maximum allowable glare index and the view angle relative to y-axis.

- **HVAC**: Under the HVAC tab, data can be inputted into the mechanical and natural ventilation; heating; cooling; humidity control; domestic hot water (DHW); mixed mode; air temperature distribution; earth tube; and cost headers. This tab allows the user to determine the heating, cooling, humidification, dehumidification and ventilation systems and cycles to be simulated. To include artificial thermal controls, the appropriate HVAC system type must be selected under the HVAC template header. The HVAC type options are based on EnergyPlus HVAC modelling which allows the user model HVAC systems in detail, without needing to draw and map out air flow networks, control systems and node connections. Under the mechanical ventilation header, data on air circulation by air conditioning systems such as fans, economisers, VAV terminal units and so on, can be inputted accordingly. The earth tube header is provided if the user intends to include HVAC by earth tube system in the model. Dehumidification and humidification are controlled per zone and depend on the HVAC type the user chooses. DesignBuilder models Domestic Hot Water using the rates of hot water consumption according to each zone's activity. DHW is activated under the Activity tab and further specified under the HVAC tab. Thus, the type and operation of DHW supply can be edited. Under the Natural Ventilation header, natural ventilation can be simulated by checking the 'on' box and setting the natural ventilation schedules. The schedule is set by zone or by minimum air flow per person data set under the Activity tab. Under the 'by zone' schedule, data can be entered to dictate the natural ventilation rate. Under the Air Temperature Distribution header, air stratification within the model can be modelled by entering data on external and internal temperatures, internal-external temperature difference, heating and cooling loads. The cost header allows the user to generate the monetrary cost of the simulated HVAC systems.

- **Generation**: The generation tab allows the user to use data for the on-site generation distribution system. When the 'include electric load centres' checkbox is checked, electric load centres (where photovoltaic and wind electrical systems, inverters and other electric storage are defined) can be accessed.

- **Outputs**: The output data of design calculations and simulations can be controlled under the outputs tab. Therefore, there are three output headers: heating design output options; cooling design output options; and simulation output options. Under the heating design and cooling design output headers, the inclusion of output data for surface temperatures, surface heat gains and losses, convective heat transfer coefficients, can be determined. The simulations output header allows the user to control what model elements for which output data will be produced. Therefore, the user can select to see data on the building zones and blocks, graphable outputs such as heat transfer and temperature levels. The graphable outputs can be represented according to environmental and comfort standards such as the standards by Fanger, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the Chartered Institution of Building Services Engineers (CIBSE) and so on. Additionally, data on annual and monthly reports, detailed daily outputs on the different aspects of the building's performance can be selected, for generation through the simulations.

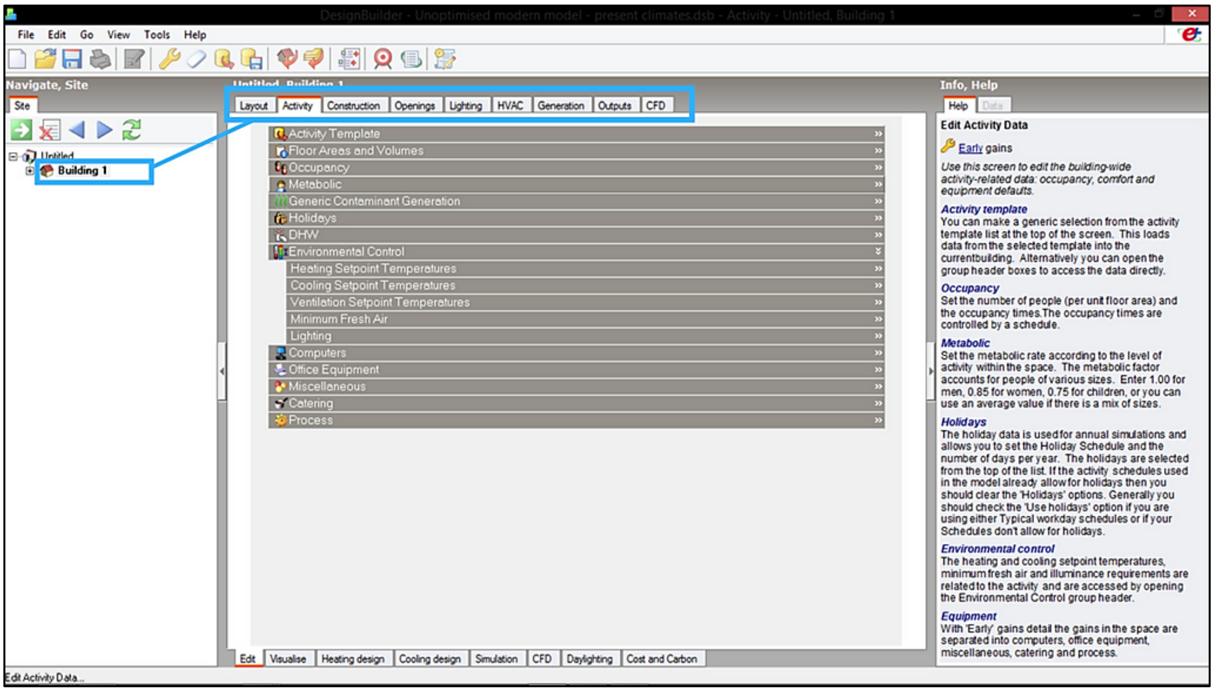


Figure 1.8 DesignBuilder interface showing builder model data tabs; source: DesignBuilder (2015).

- **CFD (computational fluid dynamics)**: The CFD tab allows the user to simulate air flow patterns within and around the model. The CFD conditions for the model or object can be reviewed and edited under this tab. The major conditions revolve around airflow rates through openings as well as surface temperatures for walls, partitions, floors, roofs, ceilings, windows, doors and sub-surfaces. The CFD Boundary Conditions Editor can be used to conveniently set the flow and temperature boundary conditions.

The above-mentioned settings are adjusted to simulate the thermal performance of south-west Nigerian traditional and contemporary house envelopes (see Figure 1.8). The contemporary house envelope is optimised, to produce a free-running version that is able to foster thermal comfort in present and future climates. Based on Szokolay's (1980; 2014) prescriptions on climatic design criteria that can influence a building's thermal performance, this study identifies the following parameters for the optimisation process:

1. Headroom height
2. External wall (thermal mass, insulation and thickness)
3. Internal ground floor (thermal mass, insulation and thickness)
4. Roof (thermal mass, pitch, structure, overhang length, covering)
5. External window (size, type, glazing thickness and type)
6. Azimuth angle (Building orientation)
7. Ground floor elevation distance

These parameters are analysed independently. With each parameter, the specification which takes the operative temperatures (indicator of thermal comfort) closer to the comfort zone, is chosen as the best specification for that parameter. As such the combination of best performing specifications across all parameters are selected when the operative temperatures are comfortably within the comfort zone in present and future climates. These specifications are combined into the design of the proposed optimised contemporary bungalow envelope, whose thermal performance is likewise simulated.

The Climatic Data Provider – Meteonorm

Meteonorm 7 is used to generate the present and future climatic data needed for this study. The Meteonorm promotional flyer (Meteonorm, n.d.) provides detailed background information about this relevant climatological software. Meteonorm is an extensive meteorological reference. It is the output of over 25 years of experience in the cultivation of meteorological databases for energy applications. Thus, Meteonorm provides climatological data of 8, 300 weather stations, with monthly mean, hourly and minute values for temperature, humidity, solar radiation, precipitation, wind speed and direction, global radiation and sunshine duration. The application provides climatic data over time periods gotten from weather station in a certain location. However, Meteonorm's intuitive Graphic User Interface (GUI) and climate models can produce the weather data of locations without any weather stations, by interpolating the data between nearby weather stations. In this way, the software can give reliable climatic data of any site worldwide. The application is very relevant in climate change research because it has access to three climate change forecasts or scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). Many studies have used Meteonorm to generate climatic data for past, present and future climate simulations (Olaniyan, Ayinla & Odetoye, 2013; Laar & Grimme, 2002; Andarini, 2014; Khalfan & Sharples, 2016). Furthermore, weather data can be exported in 36 formats, making it easy to use this software with other energy and building design applications such as DesignBuiler, which accepts the EnergyPlus Weather (EPW) file export format.

Meteonorm provides a straightforward process in generating weather data. This process is detailed in the most recent version of the software's user manual (Remund, Müller, Kunz, Huguenin-landl, Studer & Cattin, 2014). When the software is activated, the user fills a location form where the appropriate location is selected from a locations list. Next, the site orientation is inputted on the modifications form. The next form is the data form, where the user selects the type, time-period and IPCC scenario for the required weather data. After the data form is filled, the output format form comes up, where the necessary type of weather file can be selected. Once the output form is filled, the user must click 'next' to run the calculations, which last for a maximum of 10 seconds. During the calculations, monthly values are interpolated, hourly global horizontal radiation, temperature values and radiation on inclined surfaces are derived. Thereafter, the results can be saved; there is a dialog box where the monthly, daily and hourly data can be saved in different formats.

Validation – Comparing 'Virtual' and 'Live'

Generally, the concept of validity may be applied to any part of a study as it ensures that the appropriate processes are used (Kumar, 2014). 'Reliability' is related to this concept; however, reliability means "…*the quality of a measurement procedure that provides repeatability and accuracy*..." (Ibid, p.7). Validation ensures that research is done in an unbiased and objective way. Accordingly, this study uses the parallel forms method of validation for the quantitative parts of the study (Kumar, 2011). This method is applicable in establishing the accuracy of virtual environments when compared with the original case. The present climatic data derived from Meteonorm is compared with data gathered in similar live conditions.

Sampling – Representing South-west Nigerian Housing

Kumar (2011) explains the basic principles of sampling. Sampling is used in quantitative research to derive conclusions about the group from which the sample has been selected. The sample size represents the study group and is inferred based on factors considered and available resources. Generally, the larger the sample size, the better its representation of the study group. However, certain factors create deviations from the rule. One of these factors is the extent of variation in the sampling population, which applies in this study. Although large sample sizes usually accompany quantitative studies, this study has a constrained sample size. Given that the study focuses on the traditional and contemporary interpretations of south-west Nigerian housing, it was best to employ the non-random sampling method, more specifically, judgemental, or purposive sampling. The house-types that are best-suited to provide the required data, are selected based on qualitative analyses of south-west Nigerian housing.

2. Qualitative methods

Lucas (2016) discusses qualitative research, stating that it is aimed at comprehending qualities. He further states that qualitative research is well-suited to humanities-based studies such as architectural studies. This study is largely quantitative in nature but requires an initial qualitative approach to provide a meaningful context. Consequently, this study employs qualitative methods in providing a theoretical backdrop to its quantitative analyses. Essentially, the quantitative method of content analysis provides useful background information and data on the general representations of tropical housing, fundamental principles of climatic design and tropical climate change. In analysing these research themes and connecting them to its findings, this study draws on the qualitative content analysis method.

Method 3 – Content Analysis

According to Kumar (2014), content analysis is a qualitative method of manually analysing data to identify major themes related to a study's findings. Bengtsson (2016) and Hsieh & Shannon (2005) state that content analysis can be qualitative or quantitative. It seems that this method may be qualitative or quantitative depending on the nature of data being analysed – whether textual or numeric data. Hsieh & Shannon (2005) expatiate that content analysis is a research technique used to interpret meaning from the content of text data.

Sources of secondary data that were content analysed

Specifically, this study employs content analysis in extracting existing data. This study uses the directed content analysis approach to qualitatively analyse existing theory or secondary data on three major themes of this research. Kumar (2014, p.40) refers to secondary data as "…*information already collected for other purposes*…" The secondary data used in this study comprises information on tropical housing and climate change, environmental design principles, south-west Nigerian housing and climate change. This data constitutes the literature review. The author visited the University of Liverpool libraries (Sydney Jones and Harold Cohen) to source material used in developing the literature review, which provides thematic conclusions that guide this study's quantitative analysis. She found and purchased copies of relevant archived images of traditional Yoruba housing through the Frobenius-Institute online catalogue. She visited RIBA Archives (London) and The National Archives (Kew, London) for data on past housing developments in south-west Nigeria. She visited these archives on two occasions by travelling from Liverpool to London by train. The first visit was a three-day affair; the author spent the first day getting to London, the second and third days visiting the RIBA and Kew archives before returning to Liverpool. However, she found on getting back to Liverpool, her phone camera failed to record good-quality photographs of the material from The National Archives. Therefore, she visited the National Archives a second time, and made sure to use a digital camera. Using the content analysis technique, the secondary data is manually analysed by outlining themes and concepts relevant to the study. This analysis is embedded in the literature review. The literature review links this study's findings and those of earlier ones. Moreover, the literature review provides the major themes on which the study's findings are built (see Figure 1.9). The major themes which guide the development of this research, may be identified as:

1. Housing and corresponding fabrics in relation to climate and climate change in the tropics,
2. Housing and corresponding fabrics, climate and climate change in south-west Nigeria,
3. Climatic design, with focus on how the building envelope contributes to indoor thermal comfort and relates with the external climate.

Housing and corresponding fabrics in relation to climate and climate change in the tropics

The theme of housing and corresponding fabrics in relation to climate and climate change in the tropics, forms the larger research context of this study. Chapters 2 and 3 explore this theme. Chapter 2 establishes the general meaning of housing and its different dimensions according to contemporary sustainability principles. It introduces the tropical climates and its characteristics, stating the major problem of high heat and humidity. Then a broad history of housing in the tropics is discussed considering sustainability principles. This discussion then proceeds to establish the relationship between tropical housing forms, envelopes and the climate through time. Tropical climate change and all its dimensions are explored and the relationship between contemporary tropical housing and climate change is emphasised. The discussion highlights that climate change mitigation and adaptation strategies can be achieved through housing development. The main conclusions of the discussions around this theme are:

- The building envelope is the aspect of housing which relates with the external climate and determines the internal climate in the house.
- Contemporary tropical envelopes seem to generate indoor thermal discomfort and contribute to the present issue of tropical climate change primarily through active thermal controls.
- The design of the contemporary building envelope is being reviewed to resolve its poor thermal performance and reduce its contributions to climate change.
- Planned and autonomous adaptation appear to be the most effective approaches through which building designers can produce climate-responsive contemporary envelopes.
- Planned adaptation is a proactive and meditated approach to climatic design of building envelopes while autonomous approach is a reactive and spontaneous approach to climatic design of building envelopes.
- Planned adaptation can be supplemented by learning from the autonomous adaptation approach employed in the development of climate-responsive traditional envelopes.

Housing and corresponding fabrics, climate and climate change in south-west Nigeria

Issues of housing and climate change in south-west Nigeria constitute the specific context of this study. Chapters 3 and 4 deal with these issues extensively. First, climate, climate change and related issues in south-west Nigeria are identified. The relationship between housing and climate change is stated, and contemporary housing is introduced as a contributor to climate change in the region. Through an in-depth chronological examination of south-west Nigerian housing and matching envelopes, contemporary house styles are shown to be the least climate-responsive but the most socially preferred in south-west Nigeria. Many studies have indeed confirmed the poor climate-responsiveness of the contemporary house envelope. Previous authors have hinted at how this can be improved. What has been lacking is empirical research to prove the feasibility of these suggestions. Accordingly, the main conclusions from discussions on this theme include:

- There is proof of climate change in south-west Nigeria and the region’s housing is a contributor.

- The mechanical cooling systems of socially-accepted contemporary south-west housing envelopes are major causes of the region's climate change.
- There have been suggestions towards improving the climate-responsiveness of the contemporary envelope but few if any empirical research have been conducted on these issues.
- Earlier proposals that have been made are in line with the planned and autonomous adaptation.
- Amongst the different styles of housing envelopes, the most successful planned adaptation may be seen in modern house envelopes of the colonial era, and the most successful autonomous adaptation may be seen in the traditional house envelope.
- Many recommendations reflect learning from the planned and autonomous adaptation approaches in developing a climate-responsive contemporary house envelope.
- The performance of the contemporary envelope is considered only in present climates; as such it appears that there is no significant consideration of its performance in relation to climate change.

Climatic design, with focus on how the building envelope contributes to indoor thermal comfort and relates with the external climate

Issues regarding climatc design and adaptation of the building envelope are developed in Chapters 2, 5 and 6. The building envelope is defined and its major parts (roof, wall, fenestration, floor) are identified. It is observed that the building envelope creates the indoor thermal environment by its interaction with weather elements namely solar radiation, air temperature, air speed and relative humidity. As such, the way each part of the envelope interacts with these elements is detailed, by examining their thermal and structural characteristics such as thermal mass, U-values and so on. Additionally, it is asserted that thermal comfort is an indicator of how successful the building envelope is, at conditioning thermal indoor environments. Therefore, the meaning, assessment standards of thermal comfort with respect to the tropics is investigated. It is ascertained that the building envelope can achieve thermal comfort passively through climatic design features or by being supported by active mechanical thermal controls. Furthermore, two approaches to climatic design are specified: qualitative (which involves effecting design decisions on the features which adapt to the climate) and quantitative (a more rigorous approach into testing the efficiency of decisions made through the qualitative approach). Thus, the major conclusions, from discussions on the second theme, are:

- Indoor thermal comfort is an indication of a building envelope's thermal performance.

- A building envelope can successfully be developed to cultivate indoor thermal comfort through passive climatic design principles.
- A passive building envelope would not need active thermal controls which aggravate climate change.
- South-west Nigerian contemporary house envelope can be redesigned to provide thermal comfort according to passive climatic design principles (planned adaptation strategy).
- The passive climatic principles innate in south-west Nigerian traditional house envelope can be studied, and transferable design principles extracted from its climate-responsiveness (learning from autonomous adaptation).
- An attempt can be made to adapt these innate principles extracted from the traditional south-west Nigerian house-type to the contemporary south-west Nigerian house-type.
- The efficiency of the chosen design principles in promoting the climate-responsive contemporary house fabric, can be quantitatively verified by optimising the envelope according to set performance criteria of thermal comfort limits.
- Thermal simulations are an effective way of quantitatively verifying the efficient functioning of building envelopes.

Below is a list of previous studies which are fundamental to the development of this study:

1. Thiele's 2013 Sustainability studies the meaning and applications of sustainability globally. It investigates concepts such as environmental health and ecological resilience; technological potential and consequences; as well as economic and cultural aspects in sustainable development. It is a recommended text for research that addresses the environmental development issues, and this study is one of such. This source is useful in investigating this study's first research theme.

2. Tessema, Taipale & Bethge's 2009 Sustainable Buildings and Construction in Africa details practical approaches to sustainable construction in the tropics. It examined case studies of efforts at developing tropical contemporary architecture that is energy-efficient and promotes indoor environmental quality. This 2009 study guided this research by detailing how climatic design principles that inform climate-responsivenesss in traditional house envelopes, can be applied in improving contemporary house envelopes. This source informs this study's first research theme.

3. Atkinson's 1950 African Housing gives some insights into the features of traditional and colonial housing development in tropical Africa. Based on these insights, this present study was able to

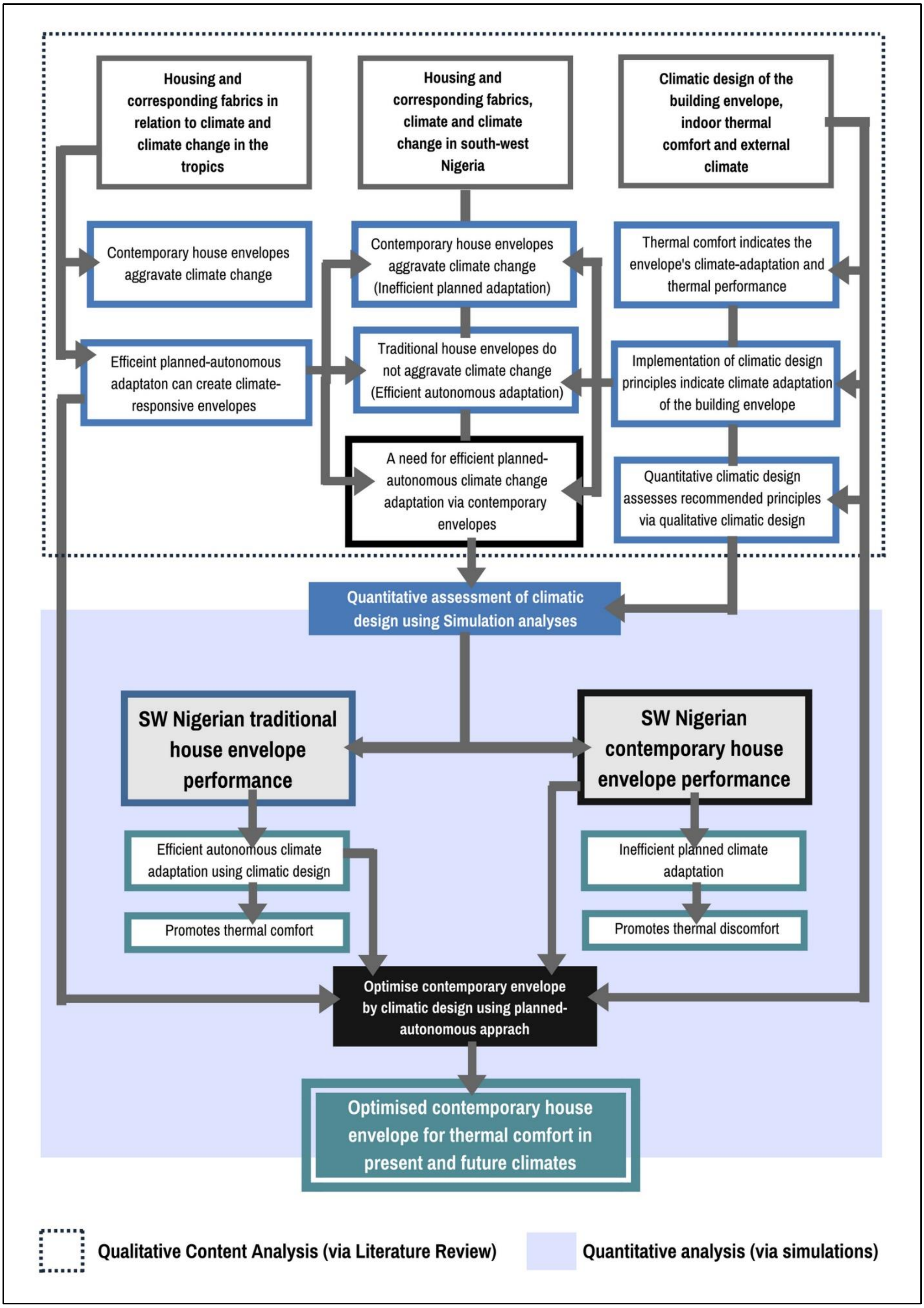


Figure 1.9 Summary of the study's methodology and methods, showing how the literature review guides the study's analysis; source: author's study.

understand basic tropical housing from pre-colonial and colonial times and establish the relevance of climate in housing developments. This source is useful for this study's first theme.

4. Danby's 1971 Design for Change helps in the development of the first research theme. It provides a concise but detailed chronological account of the evolution of tropical architecture (with reference to Africa) from pre-colonial to colonial and post-colonial periods. It highlights the shortcomings of contemporary tropical construction. The study states that sustainability principles such as climatic design, consideration of social needs, innovative approaches to communicating ideas within the tropical building industry can present solutions to these shortcomings.

5. Koenigsberger, Ingersoll, Mayhew & Szokolay's 1974 Manual of Tropical Housing and Building – Part 1: Climatic Design is an authoritative text on climatic design for tropical climates. It deals extensively with the effects of climate on the human body. It details technical design guidelines for developing house-forms that protect against adverse effects of the tropical climates. This source is fundamental in elaborating on the first and third research themes.

6. Shaw, Colley & Connell's 2007 Climate Change Adaptation by Design: A Guide for Sustainable Communities is useful in discussions around the first theme because it considers climate change adaptation, including adaptation through building design and development.

7. Short's 2017 The Recovery of Natural Environments in Architecture: Air, Comfort and Climate is one of the most relevant studies for this research. The text argues against the current practice of relying on mechanical thermal controls in conditioning contemporary indoor spaces, by emphasizing their contribution to climate change. It highlights the successes of passive thermal controls in past architecture (traditional and modernist styles) and says that the strategies can be implemented in contemporary architecture.

8. Karol & Chin Lai's 2014 Climatic design and Changing Social Needs in the Tropics: A Case Study in Kuching, Sarawak is a study that illustrates the current social preference for contemporary building envelopes in tropical regions. Its findings seem to state that it is easier to improve the climate-responsiveness of contemporary buildings are improved using climatic design, than re-popularising older house-forms. The text contributes to discussions on the first and third themes.

9. Salmon's 1999 <u>Architectural Design for Tropical Regions</u> is useful in developing the first and third research themes. This text provides insights into designing buildings that are comfortable, healthy and in consonance with the natural environment and local culture, in the tropics.

10. Butera, Adhikari & Aste's 2014 <u>Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa</u> considers the relationship between buildings in the developing world (of which the tropics are a huge part) and climate change. It deals extensively with climate-responsive and energy-efficient building design as well as eco-friendly technologies in the tropics. This text provides practical knowledge on the usefulness of simulation tools in developing climate-responsive buildings. It is useful in elaborating on the first and third research themes.

11. The 2003 and 2010 reports of the Nigerian Federal Ministry of Environment provided the necessary information on climate change in south-west Nigeria. These sources are important in reviewing the second theme.

12. The UNEP reports (n.d., 2011) from the African Ministerial Conference on the Environment (AMCEN) provided facts on climate change in Africa which were used to develop the second theme. These reports are crucial to this study as they elaborate on the various kinds of climate change mitigation and adaptation strategies which apply in the tropics. The UNEP 2009 report provides supporting information for the second theme as well.

13. UNFCCC (2007, 2014) reports detailed the different dimensions of climate change in the tropics including Nigeria. These reports give this study a robust review of tropical and south-west Nigerian climate change.

14. Akande, Fabiyi & Mark's 2015 article titled <u>Sustainable Approach to Developing Energy Efficient Buildings for Resilient Future of the Built Environment in Nigeria</u> gives some insights into the relationship between climate change and residential buildings in Nigeria. Their study is significant in developing this thesis's second theme because it revealed the current state of limited knowledge about climate change adaptation via housing development in Nigeria. Their study seems to indicate that there is a need for active research and development in climate change adaptation through Nigerian housing.

15. Olaniyan, Ayinla & Odetoye's 2015 Building Envelope vis-à-vis indoor thermal discomfort in Tropical Design: How Vulnerable are the Constituent Elements? is one of the seemingly few studies that address adaptation to present climate via south-west Nigerian contemporary house envelopes. This article is useful because it provides evidence that there is very limited research on climate change adaptation through contemporary residential envelopes in south-west Nigerian envelopes. Thus, it informs the conclusions from the second theme.

16. Denyer's 1978 African Traditional Architecture is a scholarly text which introduces African traditional architecture. It is crucial to this study's investigation of the features of south-west traditional housing, thereby contributing to the development of conclusions from the second theme.

17. Dmochowski's 1999 Introduction to Nigerian Traditional Architecture Book 2: South-West and Central Nigeria is an authoritative text on south-west Nigerian traditional architecture. Just like the previous text, it is very significant in detailing the features of south-west Nigerian traditional housing.

18. Lloyd, Mabogunje & Awe's 1967 The City of Ibadan gave tremendous insight on the urban development of the major south-west Nigerian city of Ibadan during precolonial, colonial and post-colonial times. Therefore, this study draws information on the socio-economic background, growth and features of residential architecture in Ibadan, and other south-west Nigerian cities, from this text. This source is useful in exploring discussions on the second theme.

19. Akinsemoyin & Vaughan-Richards' 1977 Building Lagos is an authority amongst studies on the historical evolution of south-west Nigerian architecture. This source provides extensive detail into housing development in the prominent south-west Nigerian city of Lagos from precolonial, colonial and post-colonial periods. It is fundamental to this study's research into the chronological and cultural development of south-west Nigerian housing and corresponding envelopes (second research theme).

20. Oyedele's (2016) article titled Assessment of Adoption of Modern Methods of Construction (MMC) in Nigeria, is a guide in discussing contemporary construction in south-west Nigeria. It helps in supporting this study's argument that contemporary house envelopes and construction are the culturally accepted in south-west Nigeria, thereby developing the second research theme.

21. Okeyinka & Amole's (2012) The Meaning of Home in Yoruba Culture is a significant study which provides the necessary evidence on the socio-cultural preference for the contemporary house (specifically the bungalow) in south-west Nigeria.

22. Adunola's (2014) Evaluation of urban residential thermal comfort in relation to indoor and outdoor air temperatures in Ibadan, Nigeria is very relevant to this research because it provides the climatic data which is used to validate this study's climatic data used in its analysis.

23. Szokolay's 2014 Introduction to Architectural Science (latest edition of his 1980 Environmental Science Handbook), is a vital reference for sustainable, bioclimatic architectural design. This text provides the basic knowledge on principles and approaches to climatic design, which this study uses in generating its results.

1.4 Main contributions of the study

The main contribution is

> **the proposal of a free-running, climate-responsive south-west Nigerian contemporary house envelope which promotes thermal comfort in the region's present and future climates.**

This proposed envelope functions solely according to climatic design principles. This research develops this prototype to show that in the wake of climate change, it is necessary and possible to design contemporary buildings, without any form of mechanical thermal controls. This proposal aligns with two studies which this author considers the most reliable and related to her research. This proposal is consistent with Short's (2017) premise that in combating climate change, contemporary buildings should be designed based on efficient passive climatic design principles. These principles enabled traditional and 20th century modernist styles, create thermally comfortable environments without any active thermal controls. Furthermore, this study's main theme is proof of Szokolay's (2014) investigation into climatic design. Szokolay states that when climatic design principles are considered, a building envelope can independently provide thermally comfortable interiors, even in hot-humid climes. This study concurs with Szokolay's stance as it used climatic design guidelines in optimising the contemporary house envelope for optimum thermal performance in present and future climates. However, this research differs from Szokolay's (1980; 2014) stance that with a massive external wall and floor, indoor day and night temperatures can be cooler in a closed heavyweight building with active controls. This research proposes that a heavyweight envelope can promote thermal comfort in a tropical climate without the support of active controls. In achieving this main contribution, this research offers other original contributions which include:

1. **Planned-autonomous adaptation to climate change through building design in south-west Nigeria**: This study utilises the planned adaptation approach in implementing climatic design principles in optimising the house envelope. However, the study considers, borrows and adapts some of the climatic design principles which are unconsciously applied through autonomous adaptation, in the design of the traditional house envelope. The result is a south-west Nigerian contemporary house envelope which promotes thermal comfort in present and future south-west Nigerian climates. By combining these two approaches (that is planned and autonomous), this study shows that planned-autonomous adaptation to climate change through building design is possible in the south-west Nigerian context. This finding is in line with UNEP reports which indicate that planned and autonomous adaptation through architectural development is an efficient way of climate change adaptation. Additionally, this study reveals that autonomous adaptation through past knowledge, should only be a guide. This is because in appraising the autonomous climate adaptation of the traditional envelope in future climates, the results showed that its climate-responsiveness is inadequate in providing thermal comfort in the future south-west Nigerian climate. It seems that the shortcoming of autonomous adaptation is that it does not pre-empt future changes but is an unconscious reaction to those changes when they have already taken place.

2. **A quantitative assessment of the south-west Nigerian traditional (Yoruba) family house envelope's thermal performance in present and future south-west Nigerian climates**: Existing literature shows that many studies on south-west Nigerian traditional housing have applied qualitative methods in examining the thermal performance of the traditional house envelope. This study undertakes its own qualitative assessments and agrees with most recognised studies such as Denyer (1978) and Dmochowski (1990). However, these examinations seem to have been made, in the context of past and/or present south-west Nigerian climatic conditions. Therefore, a major contribution of this study is a quantitative assessment of the traditional house envelope's thermal performance in present and future climates. This study provides a quantitative assessment to reinforce previous qualitative assessments on the south-west Nigerian traditional envelope. However, regarding future climates, this study's results

suggest that the proposed building envelope would not provide thermal comfort due to predicted higher temperatures. Thus, this study offers an objective assessment of the traditional house envelope's thermal performance in future climates.

3. **A quantitative assessment of the south-west Nigerian contemporary house envelope in future south-west Nigerian climates**: This study's quantitative assessment of the contemporary house envelope in present and future south-west Nigerian climates, involves evaluation of the thermal performance of the envelope in a free-running state. The results of the envelope's performance in present climates, align with previous studies on thermal performance of contemporary house envelopes such as Short (2017). Additionally, the results agree with studies on the thermal performance of south-west Nigerian contemporary house envelopes such as Adunola (2014), Akande, Fabiyi & Mark (2015) among many others. Earlier studies had tended to assert that contemporary envelopes do not foster thermal comfort in present climates. Consequently, mechanical cooling became a mandatory feature of south-west Nigerian envelope design. However, this study makes a new contribution by showing that the contemporary house envelope (as presently designed) will continue to create thermally uncomfortable environments in future climates, except if improved upon through the planned-autonomous adaptation approach.

4. **A qualitative study of the climate-responsiveness of south-west Nigerian traditional, colonial and post-colonial residential envelopes**: This study attempts to identify climate-responsiveness and climate adaptation approaches of major house envelopes from traditional, early colonial, mid-late colonial and post-colonial periods. This analysis is undertaken based on climatic design principles established by authoritative texts such as Szokolay (1980; 2014) and Koenigsberger et al (1974) as well as climate adaptation approaches detailed by UNEP reports. Through this analysis, the climate-responsiveness and climate adaptation approaches of less studied south-west Nigerian house envelopes such as the early colonial and informal house envelopes are examined.

5. **Identification of climatic design principles which are best suited to creating a climate-responsive house envelope in the south-west Nigerian context**: The optimisation of the contemporary house envelope is done under different parameters. These parameters are guided by Szokolay's (2014) study on climatic design in buildings as well as studies by Olaniyan, Ayinla & Odetoye, (2013); Adunola (2014); and Akande, Fabiyi & Mark, 2015). However, it appears that

the design principles prescribed by these studies have not been verified in the south-west Nigerian situation. This research, therefore offers a set of tested options for a climate-responsive contemporary house envelope in the south-west Nigerian context. This study notes that there are peculiarities among tropical climates, which necessitate an evaluation of the best climatic design decisions for each tropical climate's unique traits. This finding reinforces Szokolay's (2014) and Short's (2017) observation that although passive buildings exhibit the same themes of climatic design, the manner of application of design decisions depend on particular climate types. This study asserts that even amongst tropical climates, designers should carefully consider which principles are best for the particular climate.

6. **Data on contemporary and informal building designs from the south-west Nigerian region**: This study provides architectural drawings and photographs which detail the characteristics of informal and contemporary house envelopes in south-west Nigeria. During this research, the author got acquainted with a licensed and practicing architect in south-west Nigeria. By working with the architect via constant and detailed email communication, the author acquired professional architectural drawings and photographs of existing contemporary housing projects and informal settlement house-types. This material demonstrates the level of climate-responsiveness in south-west Nigerian contemporary house envelopes which this study highlights. Additionally, architectural drawings and images of the informal settlement types are provided through this study's analyses of the climate-responsiveness of key south-west Nigerian house envelopes through history, thus providing useful data.

1.5 Conclusion

This first chapter has provided a detailed background to the entire study. It has outlined where this study fits in the general body of knowledge and the gaps that it intends to fill. As such, the specific research question, objectives, methodology and methods have been discussed. Furthermore, this chapter has comprehensively explained the development of the research and its contributions to existing knowledge. At this point, the journey begins towards the realisation of a contemporary, climate-responsive, domestic building envelope in present and future south-west Nigerian climates.

Chapter 2

A 'Sustainability' perspective on the meaning of Housing and its representations in Tropical Climates

"Why do people build houses to keep the climate out, then cut holes in the walls to let it in again? I shall never understand."
Kyril Bonfiglioli, 1972

2.0 Introduction

This chapter introduces the general meaning of housing and its various aspects, within the context of sustainability. Afterwards, it investigates tropical climate classifications and housing responses in the tropics through time. Consequently, it attempts to establish the various ways through which tropical housing has always been connected to its climate by the features of the building envelope. Therefore, the building envelope is analysed, based on established environmental design principles which can affect its performance. Furthermore, this chapter shows that the performance of the building envelope is significant in determining indoor thermal comfort in the tropics. Therefore, thermal comfort is reviewed, and the accepted standards for judging thermal comfort are outlined. Summarily, the main aim of this chapter is to give a general picture of tropical housing development, especially with reference to the responses to climate within this development. It intends to establish that climate is a major consideration in the creation of housing in the tropics. In doing this, it defines the broader research areas of this study.

2.1 Definitions of Housing

Housing is a term that has several connotations. Basically, it is synonymous with the words 'shelter', 'habitat', 'abode' and has been accepted as the second most important human need after food (Jiboye, 2014). The words 'housing' and 'house' may sometimes be used interchangeably but each has a distinct meaning. Housing is more than the physical structure and its meaning can be explored on different pedestals. To an individual housing is a core component of his or her life. Studies have shown that the house provides a sense of security as the user finds their personal space from where they operate their life systems (Jiboye, 2014; Hakawa, 1983). Thus, housing contributes to the way the individual sorts out their affairs on a psychological and physical plane. Furthermore, the type of housing an individual can acquire is an indication of their quality of life. Quality, cost and availability are factors that limit prospective users in their acquisition of housing. Hence, housing can be directly related to an individual's income level. In addition, housing reflects an image of the social structure of a local community. Awotona, Mills-Tetley & Ogunshakin (1994) imply that housing, including the physical structure and the socio-economic and socio-cultural concepts behind it, are a symbol of a certain culture. Studies maintain that standards of living are higher when links between housing and other aspects of communal living are demonstrated (Bratt, 2010; Lee & Parrott, 2004). These demonstrations are seen in easy accessibility between residential areas and markets, schools and hospitals among others. It may be said that housing is the centre of a communal amenity plan. To a country, housing is an indicator of national wealth and standard of living as well as a yardstick for measuring performance in other spheres such as energy research, generation and consumption, politics and governance among others (Huiginn, 1959; Ellsworth-Krebs, Reid & Hunter, 2015). On a global scale, housing is seen as a determinant of human development. It may be said that it is an index for measuring economic progress among countries. Jiboye (2014) and Hakawa (1983) maintain that housing satisfies the basic human need for personal space which enables deliberation on life affairs. This deliberation ensures personal development which makes the individual able to contribute to societal development, promoting socio-cultural values.

2.2 Housing – Back to the Beginning

People have always needed a place of abode and protection from the elements. There is much research on the architectural description of the evolution of housing through time and two terms can be used to qualify the format in which housing has and is being expressed. 'Type' can be used to represent the spatial arrangement of the dwelling while 'style' connotes architectural expression in the design of elements and choice of materials (Monroe, Kompanek, Melton & Garlan, 1997; Güney, 2007). Although housing has developed in both style and type, architectural history indicates that today's eclectic concept of housing began very simply.

Initially, early human beings dwelt in caves and overhangs in a bid to seek protection from the elements and predators (Gamble, 2007) (see Figure 2.1). Later on, attempts at actually constructing shelter were made. The early human beings would lean leafy branches against the trunk of a tree creating a tent-like structure. Otherwise, they would arrange stones in a ring so each stone could support the bottom of a branch. There have been reports that the earliest evidence of a man-made habitat dated to before 12,000 BC when circular rings of stones were found stacked, seemingly to hold timber poles of huts or the walls of animal-skin tents, in position (Ibid). However, the earliest well-defined human dwellings date to 30 000 years ago. These structures usually followed the stone-branch principle described above and were made of natural materials such as stone and branches of trees. Around 8000 BC, circular structures made of rounded and sun-baked mud bricks with roofs, replaced the tent-like structures. In these circular dwellings, spaces were assigned to different functions more specifically. However, in this era the circle was a major feature of a typical house; examples are the circular traditional huts huts of Africa and the

Figure 2.1 Ancient cave dwellings in Cappadocia, Turkey; source: Yildiz, P. (2006, p.64).

igloos of the Eskimo (see Figure 2.2). By 2500 BC dwellings were presented with straight walls and windows. This new set of houses featured rectangular spaces, encouraging a more practical use of space. A still existing town form that era is Catal Huyuk, southern Turkey (see Figure 2.3). In the words of Gasoigne (2001),

> *Here the houses are rectangular, with windows but no doors. They adjoin each other, like cells in a honeycomb, and the entrance to each is through the roof. The windows are a happy accident, made possible by the sloping site. Each house projects a little above its neighbour, providing space for the window. Not surprisingly, an idea as excellent as this catches on elsewhere and brings with it other improvements. In a walled village or town, on a flat site, windows require the introduction of lanes and courtyards. They too will become standard features in most human settlements.*

For centuries after this era most of the major architectural development in housing was displayed throughout Europe and Asia (Ibid.). With the birth of renaissance Europe in the 17th and 18th centuries, came the Baroque-influenced residencies, English and Dutch town houses, which were a long way from the rectangular dwellings with access through the roof. Gasoigne (2001) describes the English and Dutch town houses as "*several stories high, has a narrow brick façade and generous areas of glass - made possible by the new design of sash windows*." Neoclassicism and the Gothic Revival were ushered in in the 18th and 19th centuries; domestic architecture was more impacted by the Gothic Revival than Neoclassicism. At this point, architecture in Europe had begun to influence architecture in other parts of the world. Furthermore, pure architectural types became fewer as architects began to borrow ideas from earlier styles (Frank Lloyd Wright Trust, n.d.). According to records form the Frank Lloyd Wright Trust (n.d.), the Gothic Revival style found its way to America in the 1830s and was originally used for churches but later private residencies. The style displayed asymmetry, the typical pointed windows, use of stone and wood, decorative wood trims known as bargeboard, gables and towers.

For the rest of the 19th century, houses in America, Europe and Asia showcased many different styles. According to Gasoigne (2001), the fascination with the past led to a bewildering range of historical styles. For example, the Frank Llyod Wright Trust article on Residential Architecture of the 19th and 20th centuries mentions the Italian style, derived from farm houses and villas in northern Italy, which featured "*brackets supporting overhanging eaves on shallow hip or steep gable roofs, often with a tower or belvedere…balconies, bay windows, and verandas*" and rounded windows with cornices at the head. There were also the Empire style houses with the characteristic French Mansard roof and reminiscent of Victorian, Gothic revival and classical architecture. Towards the end of the 19th century, there were the Late Picturesque styles such as the Stick, Victorian Eclectic, Shingle, Colonial Revival and Romanesque Revival styles each with its peculiar design (ibid.). Common features among these were a degree of classical ornamentation, steep roofs, plans with complex box-like rooms, verandas supported by wooden posts among others. The 20th century presented the beginnings of the 21st century standard house types and styles (see Figure 2.4). The basic detached – bungalow, and attached – duplexes, triplexes, multiplexes, row houses and apartment buildings were specifically established amid the metamorphoses of housing styles. Accordingly, the earliest forms of the typical self-contained bungalow have been traced to 17th century India. The word 'bungalow' is reported to have "originated with the British in 19th-century India, derived from the Hindustani word 'bangla' and referred to a one-story house with a surrounding porch and deep overhanging eaves" (ibid., p.7) (see Figure 2.5). It formed a basic house type in England, America, Australia and Africa through the 18th to 20th centuries (King, 1982).

The bungalow is typically a one storey house, although numerous varieties abound. The bungalow

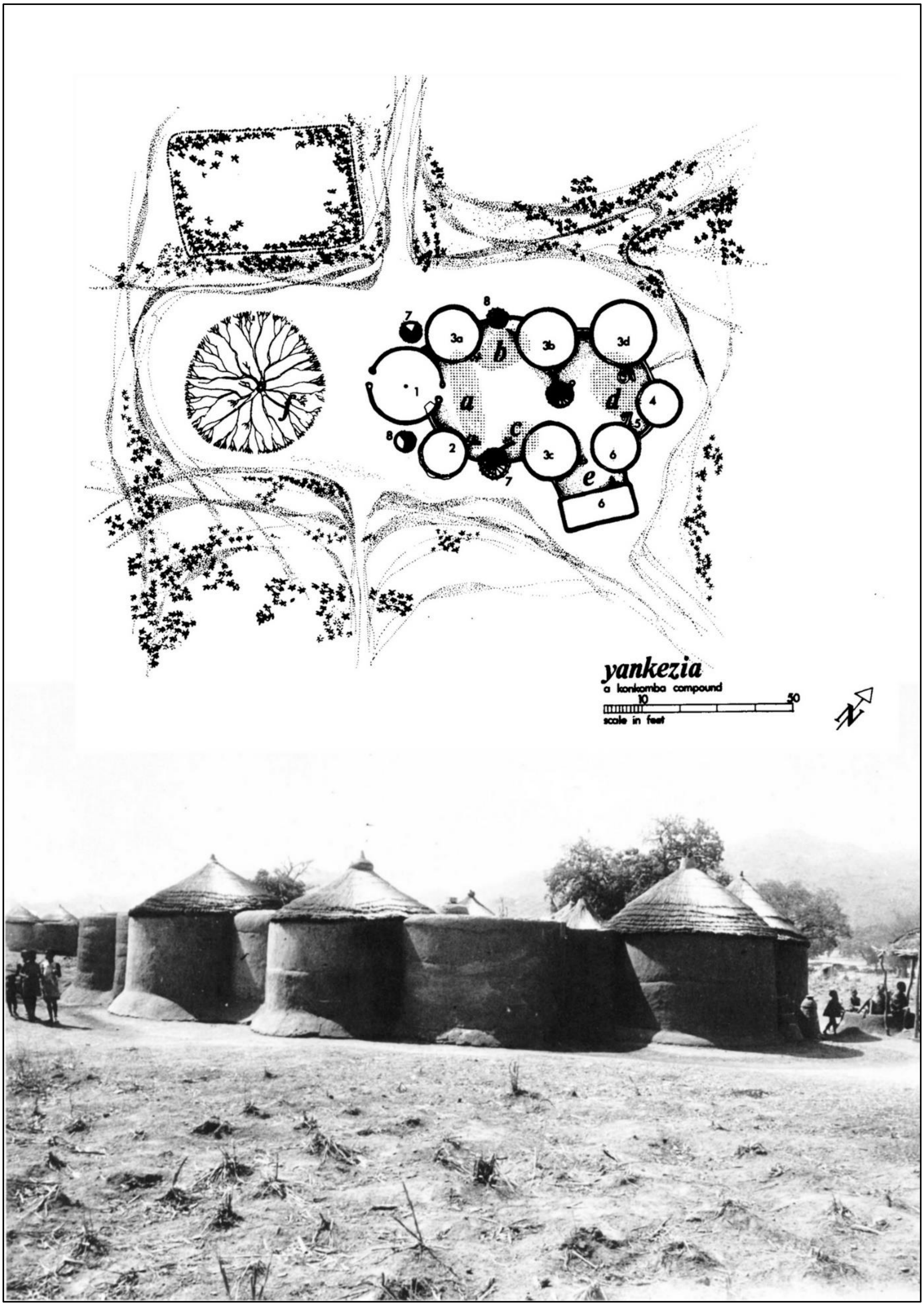


Figure 2.2 Circular huts in Tongo, northern Ghana; source: Prussin (1974, pp.191, 187).

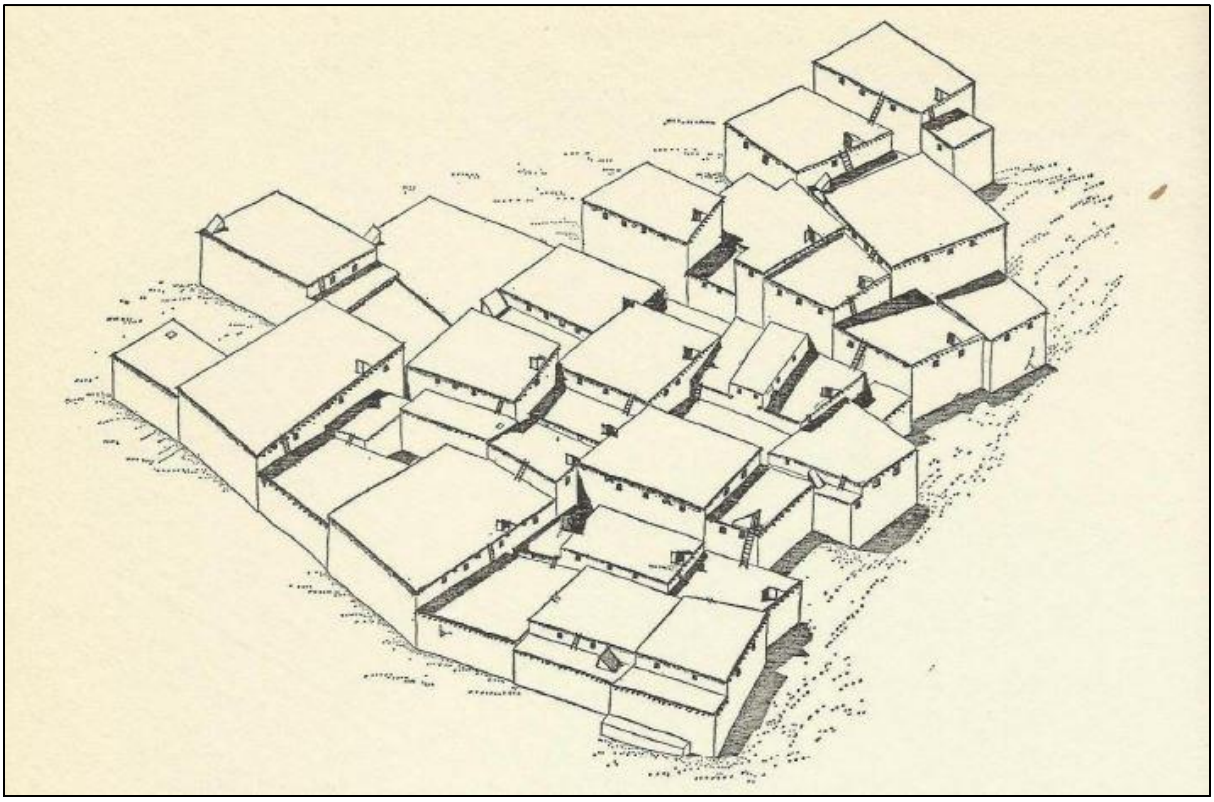


Figure 2.3 Neolithic houses in Catal Hüyük with straight walls, windows and no doors; source: Mellaart (1967, p.62).

qualifies the house-type that will be the focus of this study. By the 1910s, the bungalow house type began to evolve leading to more complex house typologies. Floor plans became more elaborate; the Frank Lloyd Wright Trust article on Residential Architecture of the 19th and 20th centuries refer to these sophisticated housing developments as the eclectic residences. The eclectic residence displayed influences from various earlier European house styles such as a basic floor plan covered be a Dutch Colonial or Spanish elevation. Such residencies are common today in urban settings where different elements of the design are redolent of a particular style. It may seem that bungalow poses as the universal symbol of a typical housing unit.

By the 1920s and 1970s, the International Style birthed flat-roofed, box-like, typically white houses, made of steel and reinforced concrete, "*which emphasised volume, regularity and order and avoided any applied ornamentation*" (Ibid., p.10). However, late 20th century modernism quickly overthrew the International Style as houses began to reflect more functional architecture that was very universal. However, these modern houses did not demonstrate meaningful symbols unlike the earlier styles and were designed without consideration of occupants' needs (Ibid.). Later, there was a movement to create more interest in architecture than was displayed by the modern style. Therefore, the post-modern style was expressed in houses that featured combinations of two distinct styles such as a mix of traditional elements with advanced forms. Furthermore, the postmodern movement created avenues for the expression of 21st architectural shifts such as sustainable architecture and hence, sustainable housing.

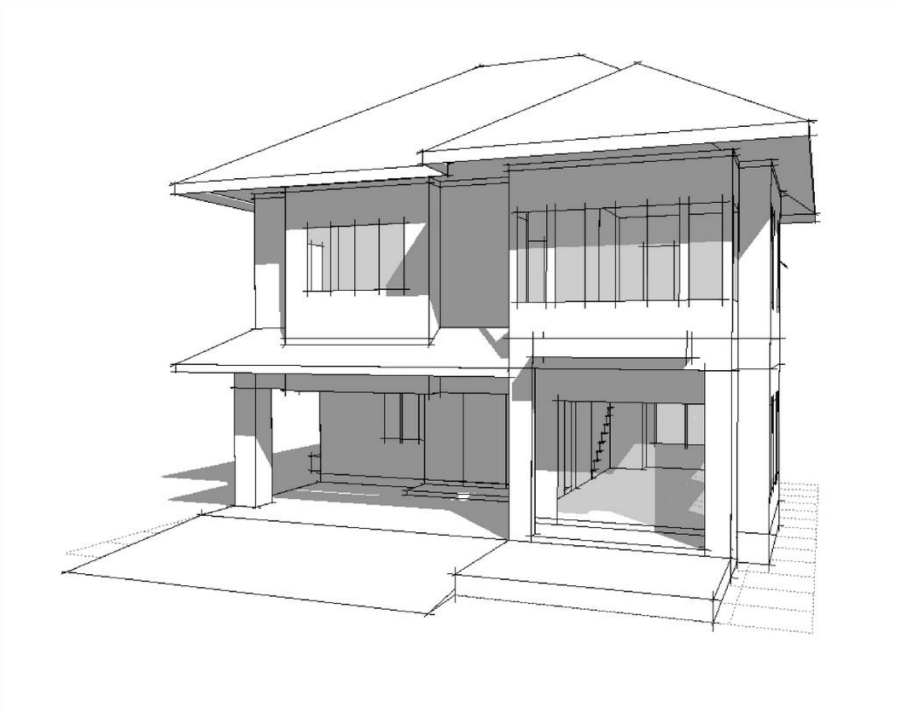


Figure 2.4 The similarities in form between 20the century housing design and 21st century housing design; source: The National Archives UK, CO 1069-290-13 "Canada" 1920-1929 (top image) and Antarikananda, Douvlou & McCartney (2006) (bottom image).

Sustainable housing is a current buzz-term and emphasises housing that is culture-specific, economical and environment-friendly (Tessema, Taipale & Bethge, 2009). With the post-modern sustainable housing movement has given rise to context-specific housing concepts among which is tropical housing which is a basic theme of this study.

Figure 2.5 A 20th century Indian bungalow; source: Bhardwaj & Garg (2016, p.607).

2.3 Housing – Present Perspectives

The previous section presented a brief architectural history of housing. However, housing can also be analysed in terms of its aspects or elements. Hence, there are physical and non-physical aspects of housing and a relationship between both aspects (Ellsworth-Krebs, Reid & Hunter, 2015; Barnes, Cullinane, Scott & Silvester, 2013) (see Figure 2.6). Accordingly, architecture is responsible for establishing the physical elements of housing which manifest as the physical milieu such as building envelopes, building utilities and so on. On the other hand, the non-physical elements of housing represent the socio-cultural and psychological processes that occur within the house (Lawrence, 2004). However, good quality housing is a product of the existence of a positive relationship between these two aspects

(Barnes et al, 2013), which are discussed in greater detail below. The existence of the non-physical and physical aspects to housing has created the popular house versus home line of reasoning. In the words of Ellsworth-Krebs, Reid & Hunter (2015, p.102):

> *…there is wide agreement of the distinction between house and home as a starting point for further exploration and development. Home is more than physical/material objects or artefacts; it is connected to emotions and relationships, as well as social and cultural expectations. By contrast, the house is just physical; it's the 'brick and mortar'. House and home stand in circular relation; interaction with physical elements… Thus, "home is a series of feelings and attachments, some of which, some of the time, and in some places, become connected to a physical structure that provides shelter".*

According to Lawrence (2004, p.2), "…the housing environment can be considered in terms of its capacity to nurture and sustain social and psychological processes." The ability for a house to reflect, maintain and at the possible best improve on the intangible lives of its occupants is a part of the setting it creates. Intangible housing comprises of health, culture and adaptability factors.

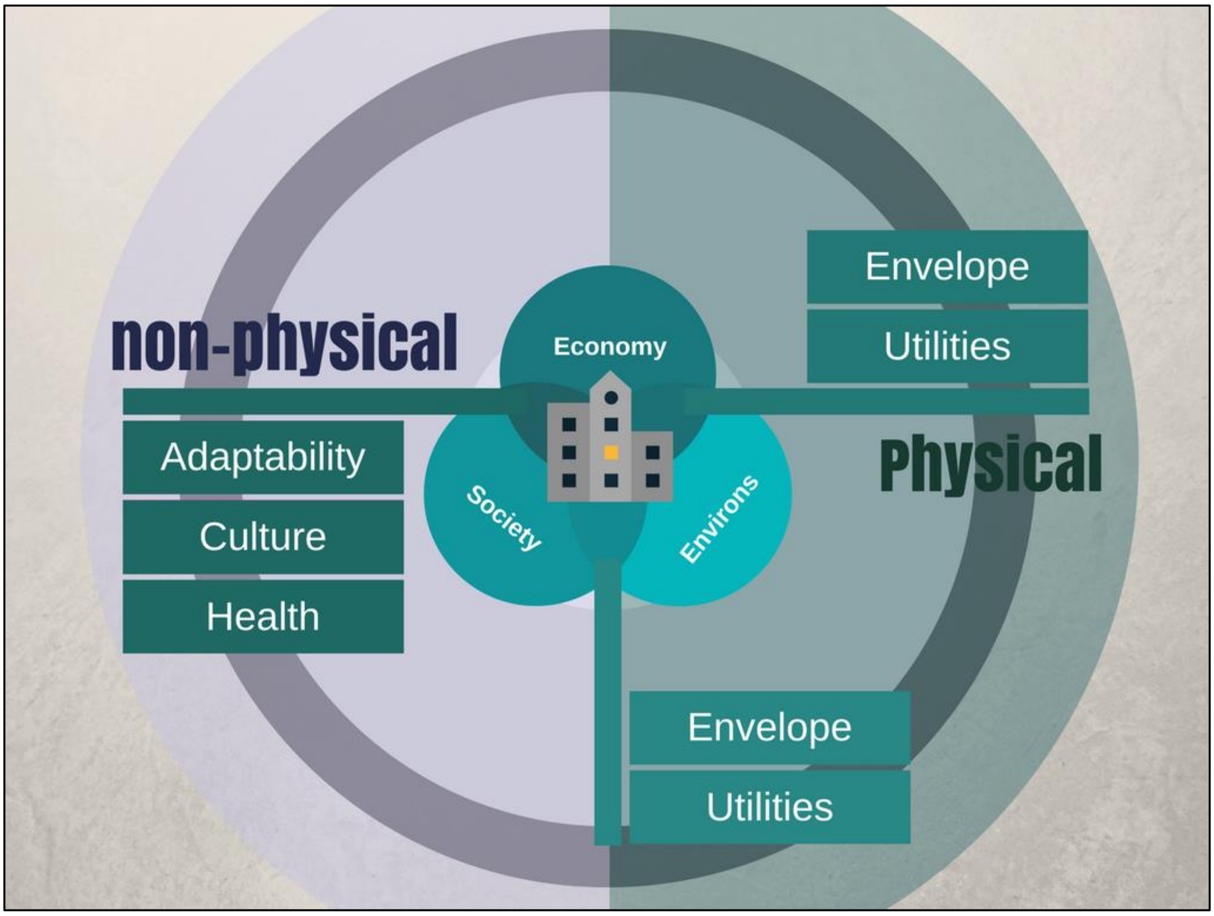


Figure 2.6 The aspects of housing in line with the three facets of sustainability; source: author's study.

2.3.1 Culture and social values

Sattler (n.d., p.5) states that the cultural element of housing manifests as an "*identification of those elements in buildings that integrate the 'affective memory' of the community…identification of building spaces that support and stimulate activities and behaviours that are typical to the communities*." The socio-cultural dimension of housing is expressed in the word 'home'. Home is the abstruse house because it represents the feelings and attachments which can be connected to the physical structure (Ellsworth-Krebs, Reid & Hunter, 2015). Consequently, in the line of Rapoport's (1998) arguments on the relationship between culture and the built environment, the house as a physical structure may be referred to as an indicator of culture. More simply put, the physical structure is borne out of the way of life of the inhabitants. Therefore, valid arguments exist that culture is the initiator of home and house. Cultural values are evident in space syntax (exhibiting concepts such as privacy and security), elements of the building structure such as decorative columns and so on (Ibid; Adedokun, 2014a). A sense of home embodied by a physical house, lays a basic foundation for a healthy way of life.

2.3.2 Occupant health and well-being

The World Health Organisation defines health as "*not merely the absence of disease and infirmity but a state of optimal physical, mental and social well-being*" (World Health Organisation, 1946). Therefore, health is manifest in three different modes: physical, mental and social, each of which finds particular expression in housing. Physical and mental health in housing is ensured through health and safety standards incorporated into the design process which produces the physical structure. These standards reflect in technical details such as choice of materials, dimensions of building components like doors and windows among others. A good example of consideration for the health of the house occupant is seen in the use of wall materials and construction that work against condensation (Barnes et al, 2013). Furthermore, housing facilitates social health through spatial syntax – the relationships between the spaces provided by the physical structure and the relationship between the house and communal facilities such as markets, schools and hospitals. Research has shown that social health is good when the arrangement of spaces within the house encourages social interaction and accessibility to communal facilities is easy, affordable and available (Adedokun, 2014a; Lawrence, 2004; Bratt, 2010). Once basic standards for health in housing are set, longevity of usage is ensured and there is ample opportunity to explore adaptability.

2.3.3 Adaptability and flexibility

This is commonly said: change is constant. Adaptability or flexibility goes along with the changes in the cultural and health needs of housing users, components of the environments within and around the physical structure. Adaptability is necessary if a certain type of housing is required for a time where requirements have evolved due to time or a change in determinants controlling those requirements. In other words, adaptability in architecture would indicate the provision of '*specific conditions to create spaces that are designed to change their functional use*" (Oikodomos, 2011, p.6). Adaptability can be explored in aspects other than spatial flexibility. This adaptive quality has been revealed in vernacular architecture where archetypes maintain a basic kind of building while adjusting to socio-economic and environmental changes throughout centuries (ibid.). Cenicacelaya & Baganha (2004) present the counter opinion that adaptability snuffs out architectural originality as being adaptable implies exploring external solutions. However, studies such as Shaw, Colley & Connell (2007) maintain that adaptability is essential for survival, as seen in biological and ecological systems.

There are many specific instances where the adaptive quality is seen in housing. North-African and Middle Eastern cultures demonstrate how socio-cultural norms influence the nature of housing; some of these tribes live in tents which can be easily disassembled for travel (Mofeed, 1963; Prussin, 2002). Modern west African city dwellers design and build their houses in such a way that more rooms can be added with increase in family size or a need to alter the use of the building in the future (Osasona, 2007a). External cultural influences have been catalysts for modifications in housing. For example, westernisation has created the spread of the International Style and the accompanying steel and glass housing features in major world cities (Salmon, 1999). Architectural adaptations to climate are being aggressively pursued presently; for instance, contemporary houses in some hot regions are being designed with larger fenestrations and more shading among others, features that were not popular before (Kamal, Wahab and Ahmad, 2004). The 'learning from the past' theme is now common as valuable lessons on how traditional buildings acclimatised to circumstantial climates (Bodach, Lang & Hamhaber, 2014). Middle eastern traditional architecture exhibits elements which facilitated comfortable indoor ambience, many of which are being incorporated in contemporary buildings design to respond to changing climates (Khalili & Amindeldar, 2014).

It can be implied from Rapoport's 1998 study on "Using culture in Housing design" that the non-physical concepts such as socio-economic structures and components, inform and are related to the nature of the built environment. It follows that standards for non-physical aspects need to be set. Hence, qualitative research methods are used to assess the non-material dimensions of housing. Lucas (2016) sheds more light on the relevance of qualitative methods in assessing abstruse theories which include the theory of home as discussed above. As non-material constructs are subject to various interpretations, he implies that qualitative research deals with the interpretation and resolution of different perspectives. Still, architecture has proven to be bridge between the conceptual and the actual in realm of built environments. Consequently, understanding the abstract concepts of housing explains the patterns in physical interpretation which is the house structure. When the physical components of buildings are explored, fundamental ones can be identified. The physical dimensions of housing are analysed accordingly.

2.3.4 Building envelope

The building envelope has been referred to as a "*large bubble that would keep the weather out and the interior climate in*" (Whole Building Design Guide, 2015). It is the enclosure of the building that protects the conditioned interior spaces from the surrounding environment, which is distinctively different from the conditioned indoor spaces (ASHRAE, 2009; Whole Building Design Guide, 2015). According to Lawal & Ojo (2011, p.584), "*the external envelope of a building is made up of the wall, roof and the floor and the amount of heat penetration into the building depends on its nature (reflectivity, absorptivity and emissivity) at the materials that made up the wall, roof and the floors*." The walls, roof and floor of a building are the building assemblies that make up the building envelope (ASHRAE, 2011) (see Figure 2.7).

Examining the building envelope draws attention to materials and construction used in producing its different components. The nature and cost of building materials, construction and labour is a relevant part of building envelope design. West (2011) provides a break-down of the well-known building economics term 'life cycle cost', indicating the types of costs associated with building. Hence, life cycle cost constitutes expenditures on the construction, operation, maintenance and end-of-life phases of building. The American Institute of Architects (2013) describes construction/capital/initial costs as the cost of materials, labour and all required to put the materials in place. Subsequently, construction costs apply to the building envelope where components such as the roof, walls, windows, doors and floors are assembled of materials and building techniques executed through human skill.

The building envelope as a bridge between the building's indoor and outdoor environments, connotes its ability to affect the relationship between both environments (Whole Building Design Guide, 2015; Salmon, 1999). The aspects of the external environment that directly impact the nature of the building envelope-and subsequently indoor living climates-are climate and topography (Olaniyan, Ayinla & Odetoye, 2013; Lawal & Ojo, 2011). Climatic elements such as solar radiation, rainfall, humidity and wind, influence indoor thermal settings, which fundamentally include air temperature and relative humidity. The indoor environmental values of air temperature and relative humidity constitute the well-known indoor environmental concept of thermal comfort (Karol & Chin Lai, 2014). The following sections discuss the specifics of these indoor and outdoor environmental variables and the way the building envelope affects the connection between both.

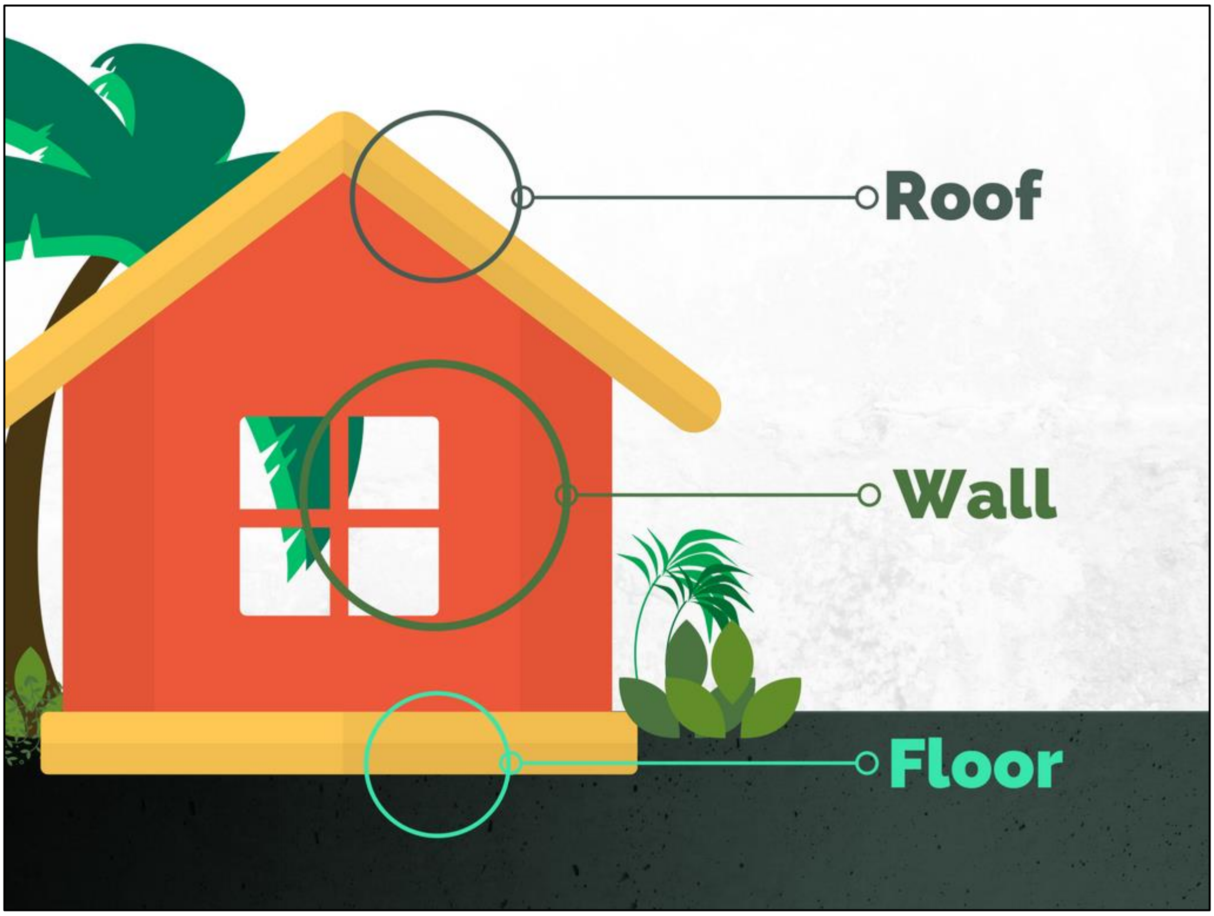


Figure 2.7 The basic components of the building envelope; source: author's study.

- **Thermal comfort**

Thermal comfort is a major indicator of a building's indoor climate. It encompasses individual factors that influence the satisfaction building occupants gain from the environment the building provides. More definitely, thermal comfort is defined as a "…*condition of mind that expresses satisfaction with the thermal environment*…" (ASHRAE, 2017, p.9.1). In addition, thermal comfort has been described as the condition where the occupant of a space does not feel too hot or too cold that is when he/she is thermally neutral (SWEGON, 2014). Therefore, thermal comfort is dependent on the interaction between the human body and the environment. According to Szokolay (1980; 2014), for thermal comfort to be achieved,

1. the deep-body temperature must be more than the skin temperature because heat flows from the deep-body to the skin;
2. The temperature of the environment must be lower than the skin temperature so that heat can be dissipated from the skin into the environment;

Accordingly, there are two basic types of factors that influence the perception of thermal comfort within a space: measurable environmental/climatic elements and subjective/personal human factors (see Table 2.1).

Table 2.1 Summary of factors affecting thermal comfort.

Environmental	Personal	Contributing factors
Air temperature	Metabolic rate (activity)	Food and drink
Air movement	Clothing	Body shape
Humidity	State of health	Subcutaneous fat
Radiation	Acclimatization	Age and gender

Source: based on Szokolay (2014)

According to Koenigsberger et al (1974) and Szokolay (1980; 2014), human factors are subjective and non-measurable. Clothing is a significant human element in determining thermal experiences. The *clo* unit defines the amount of insulation that a piece of clothing provides. The *clo* is equivalent to an average U-value of 6.5W/m^{2}K covering the entire body surface. According to Svokolay (1980):

1. Shorts, briefs, no singlet, short-sleeved shirt: 0.25 clo
2. Trousers, briefs, singlet, short-sleeved shirt: 0.67 clo
3. Lightweight business suit with cotton underwear: 1.00 clo
4. Thick winter clothing, with coat and vest: 1.95 clo
5. Heaviest arctic clothing: 4.50 clo

Szokolay (1980; 2014) details the subjective and non-measurable factors which affect the thermal preferences of a person through metabolic rate change or affecting heat dissipation processes include:

1. **Acclimatisation**: a person's physiology can get accustomed to the climate of a place or a season over a long period of time and his/her preferences are altered in this way.
2. **Age and sex**: older people prefer higher temperatures because their metabolic rates are slower; women have slower metabolic rates than men and prefer temperatures about a degree centigrade higher than the temperatures men prefer.
3. **Body shape**: a thin person prefers higher temperatures than a fleshy person because the former has a larger surface-to-volume ratio and loses more heat than the latter; additionally, the fleshy

person has more layers of fat underneath the skin which acts as insulation to the conduction of heat from deep-body to the skin.

4. **Health conditions**: a sick person has a higher metabolic heat generating rate than a healthy person; thus, a sick person would need a narrower temperature range and external processes would have to replace internal controls
5. **Level of activity**: for a person carrying out sedentary activity within still air, significant temperature changes as high as 7°C can go unnoticed; however, when rigourous activity is underway, even in windy conditions, the effect of temperature change is more pronounced.
6. **Nutrition (food and drink)**: particular foods and drinks can increase or decrease the metabolic rate.
7. **Skin colour**: According to Koenigsberger et al (1974), skin colour may influence radiation heat gains. They explain that lightest skin tones tend to reflect three times as much solar radiation as the darkest skin tones. Furthermore, dark skin tones encourage as much emission of heat from the skin as is absorbed.

Additionally, Koenigsberger et al (1974), Szokolay (1980; 2014) and Efeoma & Uduku (2014) state that thermal comfort depends on the following environmental criteria: solar radiation, air temperature (dry bulb temperature - DBT), air velocity and relative humidity (RH) (see Figure 2.8). These criteria are significant in the assessment of thermal comfort in the geographical context of this study.

- **Solar Radiation**

According to Szokolay (1980; 2014), radiation has the largest effect on thermal comfort after air temperature. He adds that there are studies which indicate that the mean radiant temperature (MRT) is twice as critical as the dry bulb temperature. Radiation involves the transfer of heat from warmer surfaces to cooler surfaces. Szokolay (1980) adds that in hot conditions, when radiation meets the skin, it creates the same feeling as warm air does. When radiation meets with a barrier to the skin such as clothing, it is converted into sensible heat which gets to the skin by conduction. Conversely, in cold conditions or when cold surfaces were in proximity, the body loses heat by radiation towards the cold surface or into the cold environment. This creates a cold sensation which may even be confused for a gush of cold air. As the sun is the universal body with the highest temperature in the universe, it emits all heat or radiation that the planet receives. According to Szokolay (2014), solar radiation can be quantified by:

a. Irradiance or intensity, which is measured in W/m^2;
b. Irradiation, the energy over a period (hour, day, month, year) measured in J/m^2 or Wh/m^2

The temperature of the sun's surface is about 6000°C. The spectrum of solar radiation reaches from 200 to 3000nm wavelengths. Three types of solar radiation can be identified:

1. Ultra-violet radiation: which has a wavelength of 200 – 380nm, and it produces photochemical effects such as sun burn, bleaching and so on;
2. Visible light: which has a wavelength of 380 – 700nm;
3. Short infra-red radiation: which has a wavelength of 700 – 3000nm and produces certain photochemical effects as well. This kind of radiation is experienced within the built environment and is emitted/absorbed by terrestrial bodies that have received solar radiation.

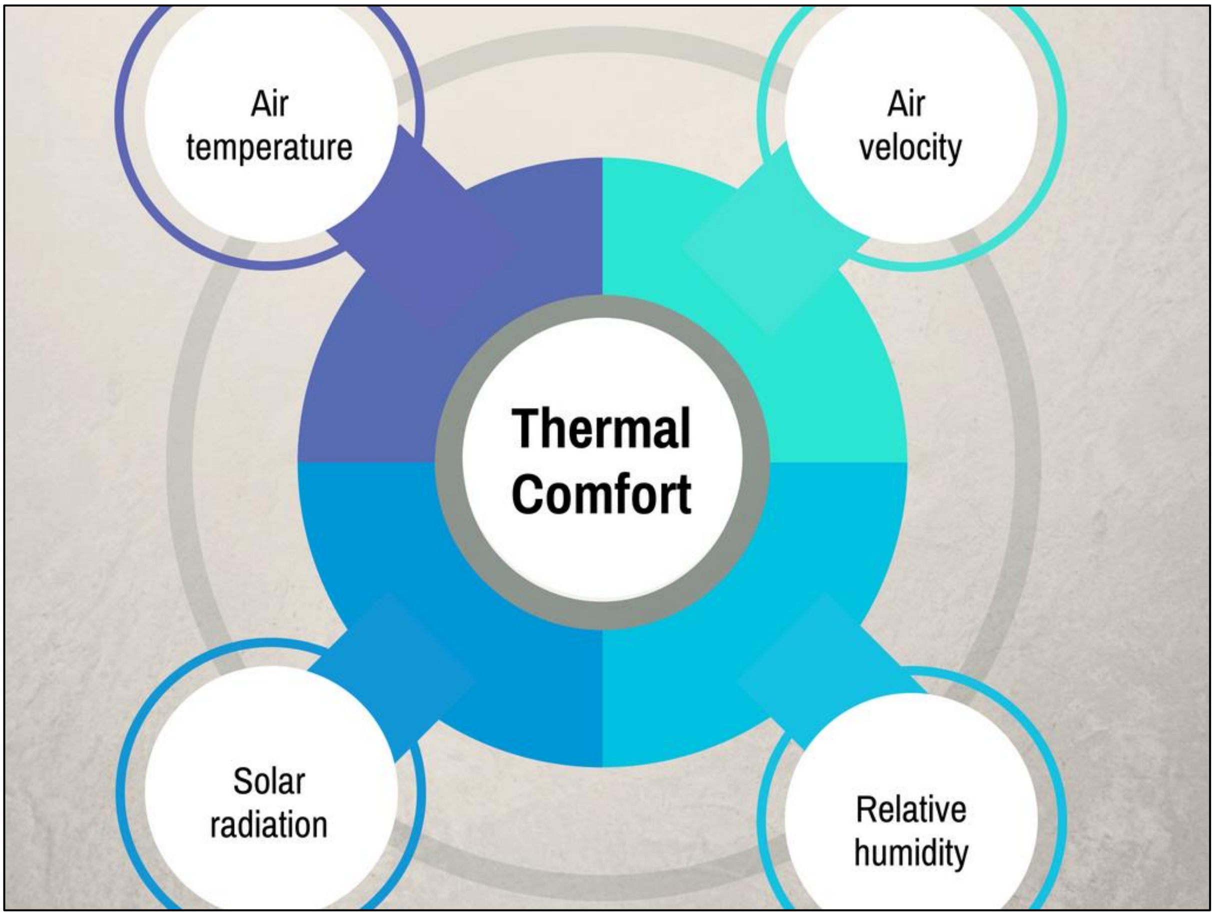


Figure 2.8 Thermal comfort and its determining environmental factors; source: author's study.

The atmospheric distribution of solar radiation types depends on altitude. Altitude fosters the sieving effect of the atmosphere, predominantly through the ozone layer and water vapour. Thus, some short-wave radiation is absorbed by the atmosphere and re-radiated at longer wavelengths.

Koenigsberger et al (1974) mention the sol-air temperature, which is used to measure the combined heating influence of radiation and warm air incident on a building surface. Therefore,

$$T_s = T_o + \frac{I \times a}{f_o} \quad [2.1]$$

where T_s = sol-air temperature in °C,

T_o = outside air temperature in °C,

I = radiation intensity, in W/m^2,

A = absorbance of the surface,

f_o = outside surface conductance i n W/m^2°C.

- **Air Temperature**

Air temperature, in simple terms, may be defined as the measure of the amount of heat in the air which is assessed with the use of a mercury thermometer, shaded by a fully ventilated Stevenson screen, 1.2 to 1.8m above the ground (Szokolay, 1980). Szokolay (2014) refers to air temperature as the most significant environmental element affecting thermal comfort. According to Koenigsberger et al (1974), Szokolay (1980; 2014), the dry bulb temperature is used to indicate air temperature. Furthermore, SWEGON (2014) maintains air temperature can be affected by other atmospheric parameters but most especially air velocity. Although, air temperature is a general measure of the hotness or coolness of the air, the operative temperature is the technically accepted concept used in assessing thermal comfort from the temperature perspective (Nowak, Nowak-Dzieszko, & Rojewska-Warchal, 2013; Clark, 2013). The operative temperature is a simplified indicator of human thermal comfort based on air temperature, mean radiant temperature and air velocity. The mean radiant temperature refers to the measure of the average temperature of the various surfaces surrounding a point, with which it shares thermal radiation (ibid). Differently, air velocity affects all measures of air temperature in a peculiar way.

- **Air velocity**

Air velocity or movement, very basically, refers to the speed of air. Szokolay (1980; 2014) provides a detailed explanation on the effect of air velocity on thermal comfort. This parameter can impact thermal comfort without changing the air temperature itself. Therefore, air velocity affects thermal comfort by:

1. Increasing convective heat loss if the moving air's temperature is less than the skin temperature; in a situation where the air is warmer than the skin, it heats up the skin and may create discomfort;
2. Speeding up evaporation, thereby providing physiological cooling. However, this effect is limited in low humidity (less than 30%) as evaporation is encouraged even when the air is still. The effect

is also restricted in high humidity (over 85%) because evaporation is not occurring, and the moving air cannot accelerate it.

The potential for air movement to accelerate evaporation and enhance thermal comfort, is highest when the humidity is average (40-50%). At this humidity, evaporation rates are good and even if the air layer above the skin gets saturated, the moving air would break this layer and ensure constant highest evaporation.

Still, the use of air for cooling is hindered by its non-thermal effects. Responses to air speeds are subjective. Szokolay (1980) reports that the common subjective responses to various air velocities include:

- 0.25m/s or less: unnoticed
- 0.25-0.50m/s: pleasant
- 0.50-1.00m/s: aware of moving air
- 1.00-1.50m/s: draughty
- More than 1.50m/s: aggravatingly draughty

The subjectivity of air velocity is evident when a speed of 1.00 m/s to 1.50m/s is pleasant for a hot environment and a speed of 0.10m/s is unnoticed and unpleasant in a heated room full of stagnant air. The application of air speed in this respect is seen in various air handling units such as air conditioners which cool a space, convector heaters which warm up spaces among others.

- **Relative humidity**

Basically, humidity refers to the presence of water vapour in the air and it is measured using a hygrometer. The specific definition of relative humidity depends on two other humidity concepts: absolute humidity (AH) and saturation humidity (SH). The absolute humidity is defined as the amount of vapour in the air which is grams of moisture per kg (g/kg) mass of dry air (Szokolay, 1980). Differently, the saturation humidity is the amount of moisture that air can hold at a given temperature. Therefore, relative humidity (RH) is defined as the humidity of air at a point, relative to the total vapour content the air can hold, at that temperature. In other words, it is a percentage of the saturation humidity. Relative humidity is expressed as a percentage.

$$\text{Relative Humidity (RH)} = AH/SH \times 100\ (\%) \qquad [2.2]$$

Air temperature is inversely proportional to relative humidity (Ibid). Therefore, as air temperature falls the moisture holding capacity reduces and relative humidity levels increase and vice versa (Butera, Adhikari & Aste, 2014). The dew point is reached when relative humidity is 100% and the air is completely saturated. With further cooling, condensation occurs. According to Koenigsberger et al (1974), Szokolay (1980; 2014) amd SWEGON (2014), air humidity has the least effect on thermal comfort. However, humidity affects the evaporative regulatory process because it determines the rate of evaporation (Fry & Drew, 1964; Koenigsberger et, 1974; Szokolay, 1980). Szokolay (1980) explains that generally, moisture evaporates quicker in dry climates than in humid climates. When temperatures are comfortable, evaporative cooling is unnecessary but when they are high, evaporation is essential to cooling. Therefore, the highest temperature under which thermal balance can be maintained depends on the humidity. For example, when the RH is 100% and the temperature is 31°C, the temperature may not incur much sweating and it can be tolerated. When the RH is 0% and the temperature is 52°C, sweating occurs and evaporation is possible; therefore, the extreme temperature can be tolerated. However, higher temperatures may not be tolerated for so long.

So far, the non-measurable and measurable determinants of thermal comfort have been identified and discussed. However, when considering the building envelope and the role it plays in determining indoor thermal environments, it is the measurable environmental factors that are most significant (Fry & Drew, 1964; Koenigsberger et al, 1974; Szokolay, 1980; 2014; SWEGON, 2014). As these indoor ambient concepts have been examined, it will be useful to investigate what parts of the building envelope are directly involved in the control of the outdoor-indoor environmental flux.

The walls, roof and floor of a building are examples of the building assemblies that make up the building envelope (ASHRAE, 2011). They are latent determinants of the thermal environment within a building because they are influential in determining heat flow from the exterior environment to the interior environment. Heat flow across the building envelope occurs by three ways: conduction, convection and radiation.

Conduction

Conduction is defined as the transfer of heat between two objects in direct contact. According to Koenigsberger et al (1974), Szokolay (1980; 2014), factors affecting conduction include:

1. The cross-sectional area (A) perpendicular to the heat flow direction, measured in m^2;
2. the thickness of the body or the length of the path of flow, measured in m;

3. the difference in temperature between the two points (the objects in contact), defined as $\Delta t = t_1 - t_2$ and measured in °C;
4. the conductivity (k-value) of the material which is the heat flow rate through a unit area and thickness of that same material, per difference in unit temperature between the two points; the k-value = Wm/m^2°C = W/m°C.

Furthemore, according to Szokolay (1980), that there are four measures linked to conduction: resistivity, resistance, conductance and transmittance.

Resistivity (r) is the reciprocal of conductivity. Therefore,

$$r = 1/k, \text{ measured in m°C/W} \qquad [2.3]$$

Resistance (R) is the product of the resistivity and thickness of a material. Therefore,

$$R = r \times b = b/k \text{ (m°C/W x m = m}^2\text{°C/W)} \qquad [2.4]$$

Conductance is the reciprocal of resistance. Therefore,

$$\text{Conductance, } C = 1/R = 1/rb \text{ (= W/ m}^2\text{°C)} \qquad [2.5]$$

When an object is multi-layered, the overall conductance is the reciprocal of the total resistance. Therefore, the individual resistances of the layers must be added. As such,

$$R = R_1 + R_2 + \ldots + R_n = r_1b_1 + r_2b_2 + \ldots + r_nb_n = b_1/k_1 + b_2k_2 + \ldots + b_n/k_n \qquad [2.6]$$

Furthermore, the conductance indicates the heat transfer property of a whole object such as a wall assembly measured between the two surfaces (Szokolay, 2014).

Transmittance/U-value is the '…*heat flow density (W/m^2) with 1 K temperature difference (DT) between air inside and air outside… in units of W/ m^{2}K.*' (Ibid, p.8). It takes account of the heat transfer property alongside the surface effects which include heat transfer by convection and radiation (Ibid). Therefore, the U-value is the most used indicator of heat transfer across envelope assemblies. Szokolay (1980) adds that the U-value of a construction depends on the composite resistances of the materials. Therefore, the choice of construction and materials can control the significance of the transmittance. Accordingly, insulated assemblies work by the principle of transmittance.

Conduction heat flow through the building (q_c) depends on the exposed area (A) and the transmittance or U-value of each element (Ibid). The rule is that to minimise conduction heat flow, the uncovered area must be as restricted as possible (Ibid). For a given object, its exposed area is influenced by its geometry. As such, among hemispherical, cuboidal and stretched oblong building shapes, the hemispherical shape has the lowest surface-to-volume area. However, the cuboid shape has the best ratio amongst quadrangular shapes and the oblong shape has the worst ratio. The implication of this surface-to-volume rule is that window areas should be as small as possible or even that walls should have no windows at all! This would inhibit lighting and ventilation and Szokolay (1980) admits this. Although, Szokolay still emphasises that the window area should be as small as possible, large windows may be permittable if other passive controls minimise the heat gains through the windows. Such passive controls include shading and glass specifications.

Furthermore, Szokolay (1980; 2014) explains the effects of insulation on conduction heat flow. He states that insulation stops heat flow through a building's thermal system. There are three types of insulation: reflective, resistive and capacitive. While reflective and resistive insulation produce immediate results, capacitive insulation operates over time.

1. **Reflective insulation:** this type of insulation is functional only within a cavity, where most of the heat transfer occurs by radiation. it is achieved by a material with low absorbance and emittance but high reflectivity such as aluminium foil.
2. **Resistive insulation**: materials used for resistive insulation act on the principle that that air is the best prevailing insulator (after a vacuum) if it is kept still. When air is kept still, convection is obviated. As such resistive insulating materials (also known as bulk materials) keep the air still; they are usually porous with a low density. Examples of bulk materials include brickwork, glass wool quilt, steel, timber, water and air.
3. **Capacitive insulation**: Capacitive insulation depends on the temperature gradient and thermal capacity of an assembly. When two surfaces of a roof, wall, floor assembly are open to different steady temperatures, a temperature gradient occurs across the thickness of the assembly, after an initial settling-down interval. If the assembly is made of one material, its temperature gradient will be linear (a straight line); however, for a multi-layer assembly, the slope of the gradient is proportional to the resistance of the layers.

Capacitive insulation creates the thermal mass effect which is one of the most important passive controls (Szokolay, 2014). Thermal mass depends on the thermal capacity of a material or an assembly. Thermal capacity is defined as the product of its mass per unit area (surface density) in kg/m^2) and its material's specific heat capacity in J/kg°C. Based on the thermal mass concept, two types of materials/construction may be identified: lightweight and heavyweight. Lightweight construction features materials that have a low mass/span ratio or low thermal mass/capacity (Lippsmeier, 1980). They possess lower embodied energy than heavyweight materials, can be processed without heavy machinery and can be easily transported over long distances (Level, 2013). Still they require more maintenance than heavyweight materials, incurring higher costs eventually. Additionally, they are less durable than heavyweight materials. Examples of lightweight materials include timber, lightweight metals such as steel, lightweight concrete, gypsum, orientated strand board, acrylic and plastic finishes, insulation: expanded polystyrene, polyurethane, and so on (Lippsmeier, 1980). Contrarily, heavyweight construction features materials that have a high mass to span ratio and thus, high heat capacity or thermal mass (Level, 2013). They are low maintenance and very long-lasting, signifying lower costs overall. However, heavyweight materials have high embodied energy and environmental impact. Examples of such materials used in heavyweight wall construction include reinforced and masonry concrete, mud brick, reverse brick veneer, tiles, rammed earth among others (Fry & Drew, 1964).

Convection

Convection is the transfer of heat from the surface of a solid to a fluid or gas and vice versa. Szokolay (1980; 2014) provides a detailed breakdown of the principles of heat flow through convection. Accordingly, the measure of heat flow by convection depends on

1. the area of contact, A, between the object and fluid, measured in m^2;
2. the temperature difference between the object and the fluid, given as $\Delta t = t_1 - t_2$ and measured in K;
3. the convection coefficient, h_c, which depends on the velocity and viscosity of the fluid and its physical makeup which ascertains if its flow is lamina or turbulent; h_c is measured in W/m^2K.

Convection applies in the heat transfer between air and a building surface.

Radiation

According to Szokolay (1980), radiation or radiant heat or thermal radiation means the infra-red wavelengths of the electromagnetic radiation spectrum (cf §2.1.1.1):

1. short infra-red, 700 – 2300 nm (0.7 – 2.3 µm),
2. long infra-red, 2.3 – 100 µm.

However, there are other wavelengths that have heat effects. The wavelength spectrum of the radiation which an object emits is affected by its temperature (Ibid; Szokolay, 2014). An object with a normal terrestrial temperature emits long infra-red (Butera, Adhikari & Aste, 2014). The sun emits short infra-red and other types of radiation with short wavelengths, ultra-violet and light.

In the transfer of radiant heat, the heat flow rate is affected by the temperatures of the radiation and receiving surfaces, as well as, on the absorbance (α) and emittance (ε) qualities of the surfaces (Szokolay, 1980; 2014). The absorbance (α) and emittance (ε) of a surface are the same for the same wavelength of radiation; however, they vary with the wavelength.

The radiation heat flow is expressed as

$$Q_r = h_r \times A \times \Delta t_1 \qquad [2.7]$$

where $\Delta t = t_1 - t_2$, and the value of h_r depends on the geometrical configuration and properties of the two surfaces.

These three methods of heat transfer determine how the different parts of the building fabric affect the indoor thermal environment. The basic parts of the building envelope and how they determine the indoor thermal environment, are discussed in the following sections.

- **Walls**

The fundamental design of walls features material choices and the type and placement of fenestrations.

- **Material choice**

The wall material can control the amount of heat that is transferred from the external environment into the interior spaces. It does so by conduction, convection and radiation. Hence walls can determine the amount of radiation absorbed, reflected or emitted. The capacity of the wall to transfer heat is expressed as its U-value. As stated earlier, the U-value depends on the thermal resistance of the specific wall material used; thus it is a reciprocal of the material's thermal resistance value or R-value. The R-value of a material of a specific thickness, is a measure of its resistance to the transfer of heat across it (Koenigsberger et al, 1974). Accordingly, the lower the U-value, the higher the material's R-value, and the more slowly heat transmission occurs making the wall a better insulator. Low U-values are aided by materials that have high thermal mass that is a tangible capacity to store heat. As stated earlier, thermal mass is directly related to heat capacity which refers to the amount of energy required to raise the temperature of material by one degree.

In the building fabric, the wall exhibits capacitive insulation best. Szokolay (1980; 2014) details how a wall can control conduction heat flow by thermal mass. The thermal capacity of a wall creates a capacitive insulation effect when there is a temperature differential (see Figure 2.9). Thus, under steady state conditions, there would be no capacitive insulation. However, outdoor temperatures are always variable even if temperatures inside are kept constant. Daily changes in temperature have a more direct effect on the capacitive insulation of a wall, than annual changes. Thus, when heat flows through the surface of a thick, heavy wall, the first layer absorbs some heat before the rest is transferred to the next layer. Thus, the transfer of heat across the total thickness of the wall, is delayed. If this time delay is as large as the diurnal temperature range, the time of the highest heat input on one surface of the wall might have passed before the heat gets to the other side. By this time, most of the heat would have been absorbed by the outer layers before getting to the inner layers. Some of the heat absorbed by the layers can flow back and be emitted on both sides.

Furthermore, when there is heat input on one face on the wall (usually from outside), the rate at which the heat travels across its thickness is determined by:

1. The conductivity (k): if the conductivity of the material is high, the rate will be quicker;
2. The density (ρ) and specific heat capacity (c_p): if the density and specific heat capacity are high, the rate will be slower.

Summarily, the higher the thermal mass, the higher the heat capacity; thus, the thermal mass of the wall might trump the U-value. Therefore, a material might have a low U-value but low heat capacity making it easy for the surface to heat up and allow heat transfer by radiation. Furthermore, the degrees of the reflectivity, absorptivity and emissivity of the surfaces of the wall material affect the degree of heat transfer across the wall. If heat transfer across the wall is controlled, the wall functions as a productive passive indoor climate-conditioning element.

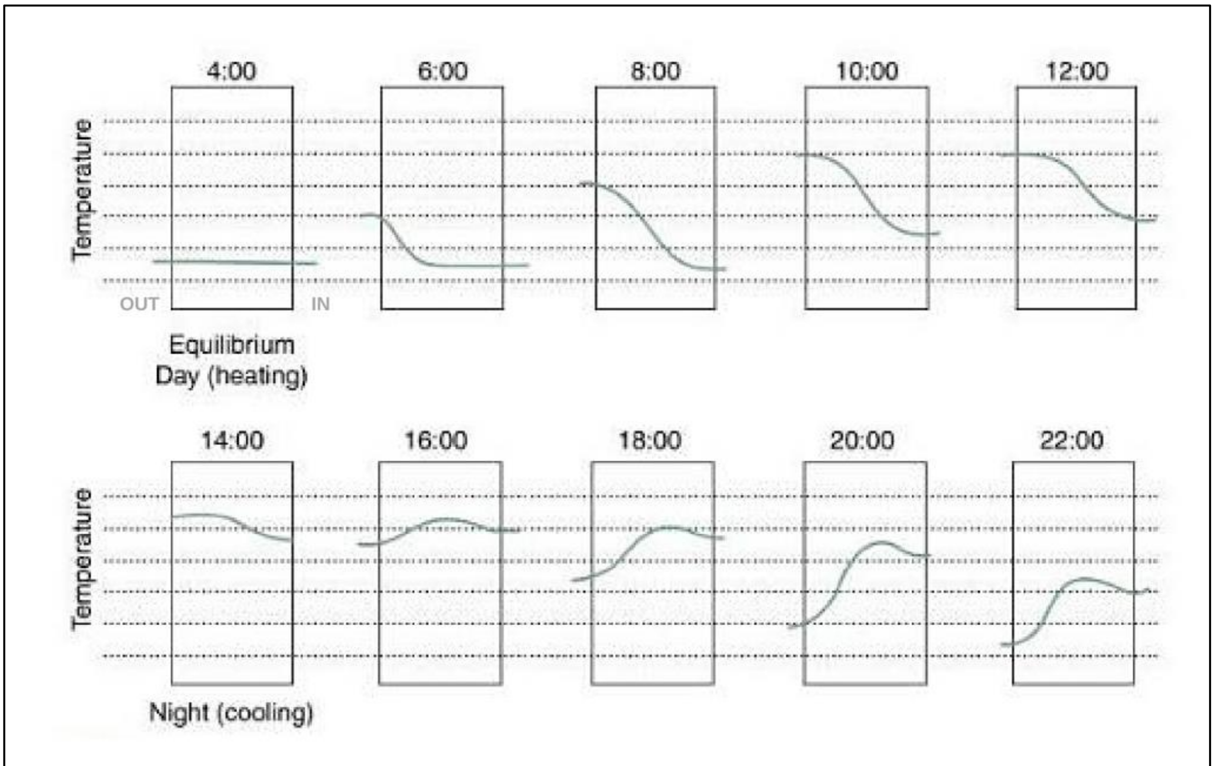


Figure 2.9 Time sequence of temperature gradients across a wall due to capacitive insulation/thermal mass; source: Szokolay (2014).

- **Fenestration**

ASHRAE (2009, p.354) defines 'fenestration' as "*an architectural term that refers to the arrangement, proportion and design of window, skylight and door systems in a building*." Fenestrations help to create visual/physical connections to outdoor spaces, admit daylight, control radiation, heat gain and air flow (ibid). As this study focuses on controlling thermal comfort, the manner through which windows affect indoor temperatures by primarily solar heat gain and minimally, air flow will be analysed. The type, materials, position and number of windows in a space affect its capacity to moderate the indoor climate of that space (Center for Climate and Energy Solutions (C2ES), 2011). More specifically, solar heat gain is determined by window size, glazing material and orientation (Szokolay, 1980; 2014). Thus, the solar heat gain for windows is expressed as

$$Q_s = A \times G \times \Theta \qquad [2.8]$$

Where A = window area;

G = irradiance value on a vertical plane;

ϴ = solar gain factor or solar heat gain coefficient (American term).

Typically, the components of a contemporary window include the glazing material which may be glass or plastic and the framing; usually, other parts make up a standard window such as mullions, muntin bars and so on, depending on the window type. In order to assess the ability of windows to control thermal comfort, two concepts are important: the U-factor and solar gain factor (SGF).

The U-factor is a measure of how much heat a window admits into a space (Autodesk, 2011). It depends on the thermal transmittance of the certain components of the window which include the center-of-glass, edge-of-glass and frame (ASHRAE, 2009). On the other hand, the SGF measures much solar radiation is absorbed into the building through the window against what amount is reflected away (Ibid). According to Szokolay (1980; 2014), it is the sum of the proportions of transmission, absorption and reflectance of solar radiation by the window. These proportions are expressed as the following coefficients:

ρ = reflectance

τ = transmittance

α = absorbance

Therefore, a window's solar heat gain factor is technically the sum of these three coefficients:

$$\rho + \tau + \alpha = 1 \qquad [2.9]$$

Accordingly, the SGF depends on all the parts of the window and is a dimensionless number between one and zero (Autodesk, 2011). The window choice for optimum thermal experiences in a climatic context is fundamentally judged based on these two concepts. Koenigsberger et al (1974) and Butera, Adhikari & Aste (2014) add that window glass is transparent for short-wave, infra-red radiation (with wavelengths less than 2.5 microns) from the sun. Therefore, glass easily admits infra-red radiation into the interior spaces. Indoor objects absorb these wave lengths, heat up and reradiate long waves or thermal radiation (with wavelengths more than 2.5 microns). However, window glass is opaque for the long-wave radiation given off by objects inside the house. As such, long-wave radiation remains within the interior spaces. Consequently, the indoor temperatures can rise well above the outdoor temperatures, because of the accumulated radiation inside the space. Hence, the greatest heat gains can occur through the amount of solar radiation transmitted through a window.

In addition, windows regulate ventilation in spaces. Ventilation is the natural or mechanical intentional introduction of air from the outside into a building (ASHRAE, 2009). Mechanical ventilation is achieved through active thermal conditioning systems. However, natural ventilation is the flow of air through fenestration systems, which can be facilitated by natural and/or artificially produced pressure differentials (ibid). When considering the role of windows in harnessing air speed for ventilation, Szokolay (1980; 2014) states that windows should be large and positioned in the direction of prevailing winds. These would facilitate maximum ventilation. Ventilation by pressure differentials is the underlying principle for the stack effect. The stack effect is controlled by thermal forces which are the product of the stack cross-sectional area and the stack pressure (Koenigsberger et al, 1974) (see Figure 2.10). Szokolay (1980; 2014) elaborates that the stack effect takes advantage of temperature and density differences between the exterior and interior air. When the room is warmer than the outdoor air, a low-level access and high-level exit for air can be provided. These access and exit points are typically windows but might be other fenestration types such as vents. Cooler and denser air from outside enters through the low-level access and cools the occupied area close to the floor. Due to internal heat gains, the air warms up, gets lighter and rises. The warm air layer is close to the ceiling, typically an unoccupied area and eventually exits the room through the high-level outlet. Therefore, the stack pressure is a key component affected by the vertical distance between the inlet and outlet, as well as the temperature difference (Koenigsberger et al, 1974).

However, Koenigsberger et al (1974) stipulate that reliance on thermal forces to bring about substantial air movements is inadequate. Therefore, the effects of available winds must be considered. In this regard, a thorough understanding of the air flow through and around a building as well as the factors influencing the phenomenon, are necessary. Koenigsberger et al (1974) expatiate that air flow patterns can only be predicted using experimental rules gotten from calculations of wind flow in real buildings or wind tunnel analyses. Adequate ventilation helps with temperature and humidity control as the introduction of cool

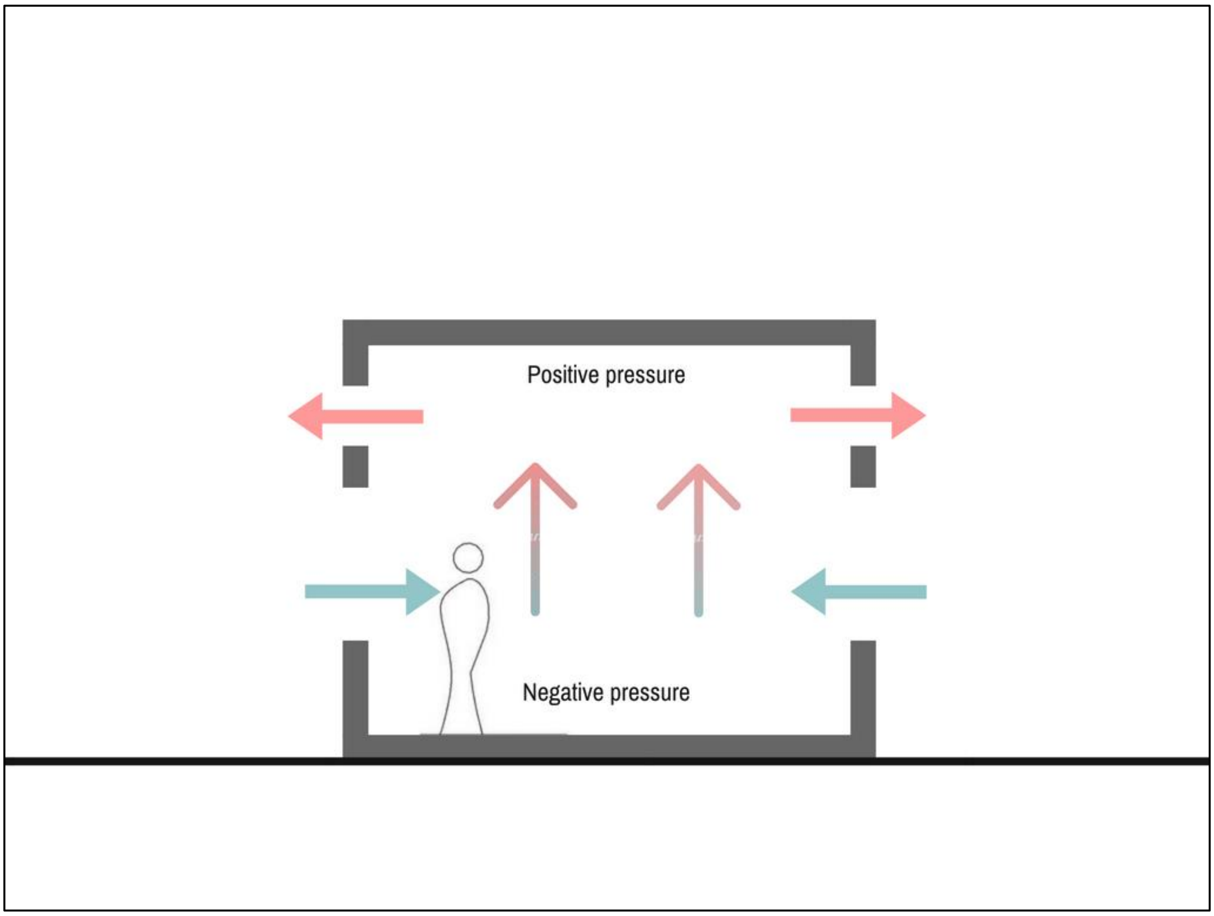


Figure 2.10 Stack effect showing pressure differential; source: author's study.

air can displace warm air and dry air moving at high speed can dislodge damp air. Short (2017) emphasises the role of ventilation in creating 'good air' within a building. As wind flows through the building, air contaminants such as odours, small particles such as dust, carbonic acid and so on are expelled, replacing used 'bad' air with fresh 'good' air. This hints at the link between the physical (building envelope performance) and the non-physical aspects (occupant health and well-being) of housing. Nevertheless, windows as natural ventilation systems can be harnessed to control air flow thereby controlling thermal comfort.

The walls and exterior windows seem to be the most popular building envelope elements in thermal comfort assessment across climates. However, the other fundamental parts of the building envelope have a significant role to play. The floor of a building is another part of the building envelope.

- **Floors**

The floors of buildings are constructed for structural support and environmental control (Whole Building Design Guide, 2011). Basically, the structure and materials used for floors affect the indoor climate conditions by heat and moisture control. According to Szokolay (1980; 2014) floors can absorb solar heat gain; thus they can control heat levels by thermal mass (see Figure 2.11). Furthermore, a floor can transfer heat or cold to the air by convection, depending on how much heat it absorbs. Mallick (1996) states that ground floors in contact with the ground, can easily transfer absorbed heat to the ground by conduction heat flow.

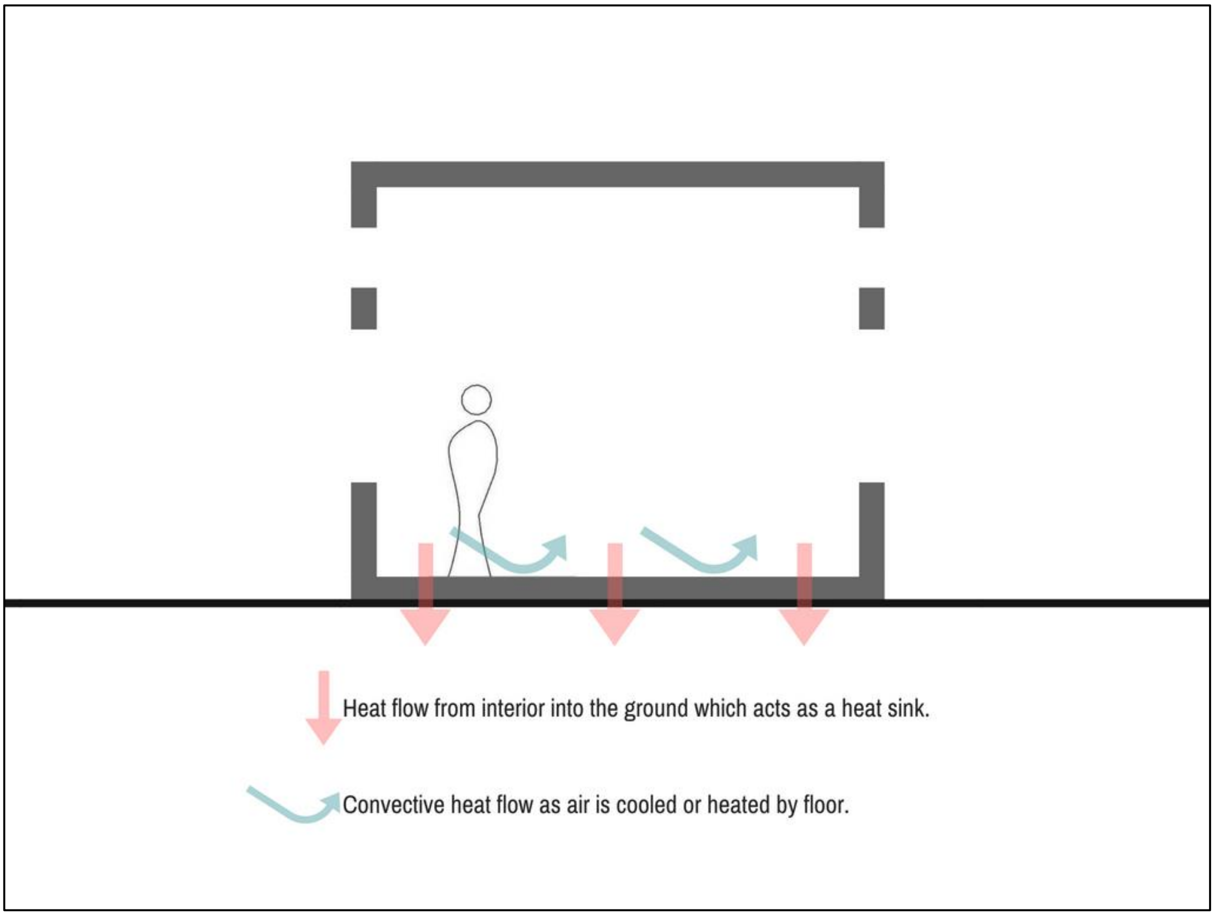


Figure 2.11 Heat flow through the floor of a building; source: author's study.

- **Roofs**

Roofs have a tangible role to play in controlling temperature and ventilation within indoor spaces (C2ES, 2011). The roof is the part of the building envelope that receives the most solar radiation therefore its thermal performance substantially affects indoor temperatures (see Figure 2.12). Butera, Adhikari & Aste, (2014, p.57) explain that

> *The outer surface absorbs radiation and heats up; the roof then transmits this heat to its inner surface, which increases in temperature, radiating inwards,*

> *heating up the indoor air, and finally being absorbed by the occupants and objects inside. The thermal performance of the roof is critical for thermal comfort.*

More specifically, the thermal performance of a roof depends on its shape, construction and the nature of materials used (thermal mass) (Ibid). Hence, the air temperature in a space is affected by several factors including the type of ceiling and the type of roof covering, which are parts of the roof structure (ASHRAE, 2011; Butera, Adhikari & Aste, 2014). Furthermore, roof overhangs help with temperature control by shading walls, fenestrations and indoor spaces from direct solar radiation, thereby reducing conductive, convective and radiative heat gains through the walls and fenestrations (Bodach, Lang & Hamhaber, 2014; Karol & Chin Lai, 2014) (see Figure 2.12). The shape and structure of the roof can affect the degree of ventilation it experiences (see Figure 2.13). Ventilation within the roof is critical (especially in hot climates) because it helps to cool the roof and subsequently cool indoor air (ibid). Natural ventilation can be encouraged by the construction of ventilated roofs which have air spaces and openings at different heights to take advantage of the stack effect. The stack effect would work when higher ceilings allow lighter warmer air rise above while cooler denser air remains below where occupants are, promoting cooling and comfort.

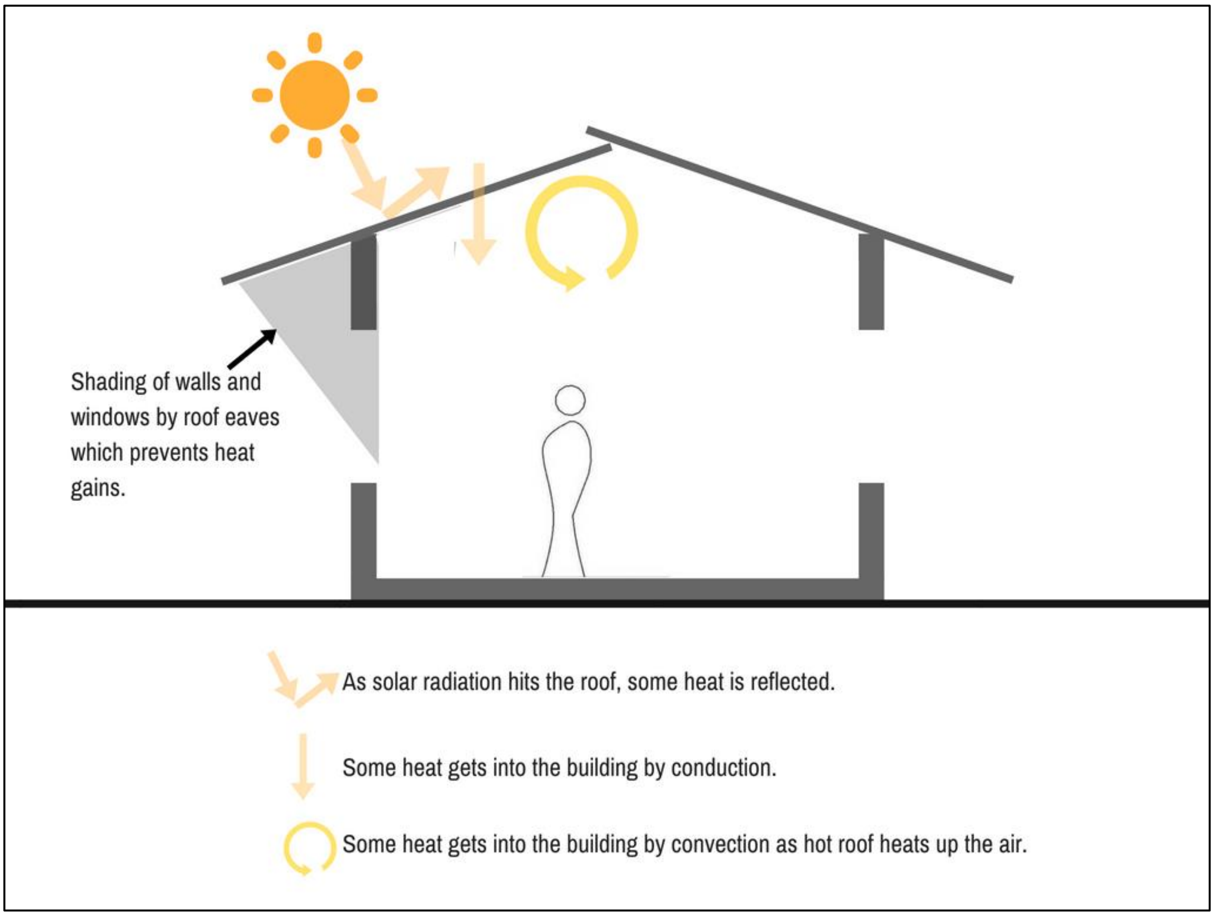


Figure 2.12 Heat flow through the roof of a building; source: author's study.

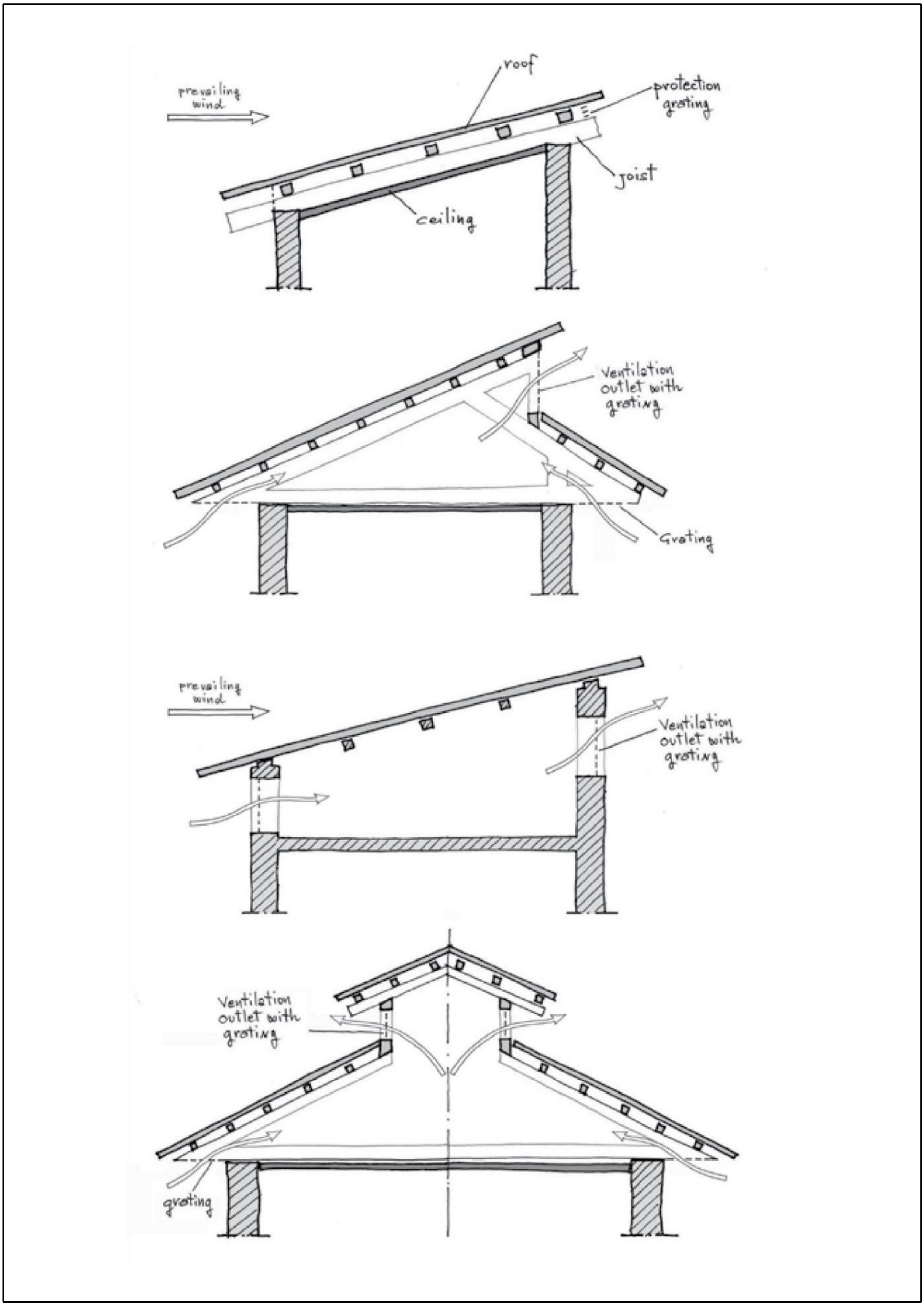


Figure 2.13 Ventilation of the roof according to different structures; source: Butera, Adhikari & Aste (2014, p.59).

Another dimension to the environment-building envelope relationship is the environmental impact of materials in terms of sources and carbon emissions. Eco-friendliness is a buzz word when considering materials for construction presently (Latha, Darshana, & Venugopal, 2015). Professionals in the building industry have become acquainted with terms that qualify the eco-friendliness/ influence of construction material specifications on the biosphere. One of the most relevant of these terms is 'embodied carbon'. Anderson (n.d., p.2) defines 'embodied carbon' as "*the total quantity of carbon dioxide emitted from burning fossil fuels to manufacture both the product and all the raw materials it uses; it also includes other emissions from manufacturing processes…the emissions of other greenhouse gases (GHGs) such as the emission of methane, nitrous oxide (N2O) or HCFCs*." Embodied carbon of materials indicates the contribution of that particular product to climate change-a contemporary concern-which will be elaborated on later on in the study (Thiele, 2013). Other properties such as moisture absorptiveness, fire resistance, durability, expansion and contraction reflect the suitability of construction materials to the external environment (Egenti, Khatib & Oloke, 2014; Fry and Drew, 1964; Latha, Darshana & Venugopal, 2015). These principles are becoming increasingly pertinent in the evaluation and use of building materials. Additionally, in certain regions, the topography of the environment influences the form of the building, and consequently the structure of the building envelope. Many dwellings in riverine areas are built on stilts, based in the water (Danby, 1971; Kamal, Wahab & Ahmad, 2004). Other types possess foundations modified to the terrain or soil type of the location (Bodach, Lang & Hamhaber, 2014). Furthermore, houses built along the slopes of mountains or hills, tend to have sections built into the slope, elongated forms or varying levels (ibid.). Notably, the forms generated due to modifications inspired by the landform, can surreptitiously determine indoor thermal ambience. The 2017 *ASHRAE Fundamentals* hand book states that topography can be used to redirect air flow, thereby initiating natural cooling in hot climates.

Accordingly, the physique of a house fits with the basic building envelope description and all it entails. The building envelope may be described as the skeleton of the house as other systems that help with temperature control, water supply, lighting, and ventilation are integrated with it.

2.3.5 Building services (utilities)

While the building envelope effectively meets the need for shelter, building services are the processes integrated into a building envelope to make housing efficient. Hall & Greeno (2009, p.17) expatiate by defining building services as the unavoidable "…*dynamics in a static structure, providing movement, communications, facilities and comfort*…" Building services ensure that a building is 'alive' as they are to a structure what biological systems are to a living body (see Figure 2.14). The broad bracket of building services includes building control; energy supply and distribution; escalators and lifts; façade engineering; fire safety; detection and protection; heating, ventilation and cooling; information and communications technology (ICT) networks; lighting; lightning protection; refrigeration; security systems; water supply; drainage and plumbing and carbon emissions management (Ibid). Furthermore, certain housing needs might require specialist systems which require peculiar design and accompanying costs. The issue of costing arises here; construction (installation), operation and maintenance costs exist when considering building services. West (2011) and the AIA (2013) explain that these costs indicate expenditures on labour (human skill) and equipment, essential in setting up these utilities and ensuring that they run well during the period of building use.

Noteworthy when considering building utilities is the dimension that addresses the environment. These utility systems are powered by energy sources which are usually derived from the environment (ASHRAE, 2009). For example, water supply systems channel water from underground, rivers, streams, reservoirs and so on; lighting systems run on electricity, gas (Thiele, 2013). Hence natural resources can be used up in maintaining building services (IRENA, 2013). Even more, the mode of operations of these utilities features a release of waste -which could be in gas, liquid or solid form-into the environment (Seyfang, 2010; Thiele, 2013). This is the relationship between building utilities and the environment and research has shown that in this relationship, the latter is, often, disadvantaged (Omole & Ndambuki, 2014). For example, many electrical and mechanical systems run on fossil fuels, an energy source which is linked

Figure 2.14 An example of HVAC building services; source: Feit (2018).

to resource depletion and greenhouse gas emission (Hall & Greeno, 2009). Therefore, there is a current sensitisation in the construction industry to the environmental impact of building services provision in all kinds of buildings, including housing. The basic utilities that exist in houses include heating, ventilation and air conditioning (HVAC) systems, appliance-energy, lighting and water supply systems. HVAC systems are regarded as the active thermal controls of a building's indoor environment (Szokolay, 1980; 2014). Szokolay (1980) defines active controls as the different thermal installations for heating, ventilation and air conditioning, which run on energy inputs. Currently, there is a huge emphasis on developing and employing housing utilities that do not threaten the availability of natural resources and upset natural ecological and atmospheric balance (IRENA, 2013; Monforti, 2011; Omole & Ndambuki, 2014).

The building envelope and its utilities can be said to constitute the physical aspects of housing, which are definite. Therefore, unlike the abstract concepts of housing, they can be studied quantitatively. Accordingly, Lucas (2016) confirms that quantitative research methods are objective where large amounts of data are analysed for patterns which establish rules. The performance of building envelope and utilities is a very vibrant area of quantitative research as standards are needed for physical housing in different contexts (Butera, Adhikari & Aste, 2014). Quantitative tools used in assessing housing quality range from realistic field surveys to virtual computer simulations. Egenti, Khatib & Oloke (2014) affirm that to practically identify patterns in housing, they used the quantitative field survey tool. Thus, it may be said that the quality of physical house is usually measured and determined objectively.

However, it can be argued that each one dimension of housing cannot exist without the other. Ellsworth-Krebs, Reid & Hunter (2015, p.102) state that "*house and home stand in circular relation; interactions with physical elements…are integral to attaining a sense of home*…" In addition, the physical structure can influence the non-physical aspects of housing. Barnes et al (2013) explain that the material components of housing can affect occupant health when, for instance, families have to cope with the stress of living in cold and damp conditions. Housing starts with the intangible nuggets of a certain manner of living, which is accompanied by needs: the need for a space where psychological processes can be resolved and sense of place, identity and so on, apart from the fundamental need for shelter (Jiboye, 2014). The concrete expression of housing erupts from these non-physical foundations as the physical structure termed 'house' or 'abode' or 'dwelling'. Consequently, the house is a communicator of socio-cultural and economic processes, which may be never be understood and preserved unless expressed in relatable forms.

Interestingly, the aspects of housing fit with Tessema, Taipale & Bethge's (2009) perceptions of sustainable housing. The non-physical aspects of housing – socio-culture, wellbeing, adaptability - find place in the social dimension of sustainable housing. On the other hand, the physical aspects – building envelope, materials, construction and systems -are linked to the economic and environmental dimensions of sustainable housing. In this way, it can be said that there is a standard especially now, which governs the production of housing. Thus, the sustainability-housing perspective has become the foundation on which critical analyses of housing have been built (Salmon, 1999; Fry & Drew, 1964). It is an intriguing notion that the concept of sustainability has a subtle link to time. According to ASHRAE (2009; 2011) and Seyfang (2010) sustainability addresses the needs of the present without compromising those of the future. This implies that sustainability emphasises profitable development with societal and environmental changes through time. Moreover, it may be argued that sustainability considers the past as its principles draw insight from historical phenomena (Butera, Adhikari & Aste, 2014; Cenicacelaya & Baganha, 2004). Therefore, the sustainability-time element finds expression in sustainable housing where common themes are learning from traditional housing responses, identifying present housing needs and ensuring present solutions are relevant in the future.

The previous discussions have shown that housing is the interaction between house and home. They have shown that in current times, the principles of sustainable development have been established to guide these interactions. Within these threads of discussion, it may be observed that, through the building envelope, the house interacts with the external climate. As, this study focuses on the house as it exists in tropical south-western Nigeria, the features of the tropical climate are explored next.

2.4 The Sunny Situations - Tropical climates

'Climate' is a much-used word now as it is linked to major global issues – housing, agriculture, ecology among others. Climate change is the renowned climate-based subject and it is a major theme of this study. A proper understanding of a pivotal concept is important, however, especially when so many subject-matters are linked to that particular concept. Therefore, climate is fundamentally the "*long-term average weather conditions (usually taken over a period of more than 30 years…) of a region including typical weather patterns such as the frequency and intensity of storms, cold spells and heat waves*." (UNEP, 2011, p.4). It is apparent that weather and climate are closely associated. Baede, Ahlonsou, Ding & Schimel, (n.d.) expatiate that weather refers to atmospheric changes based on environmental elements such as cloud cover, precipitation, humidity, wind, temperature and so on. Furthermore, weather conditions can be predicted to a certain extent while climate becomes associated with a particular place over extensive periods of time (ibid). Climate is determined by latitude, geography and topography, distance from the sea and so on (UNEP, 2011; Baede et al., n.d.). It follows that differences in the features of regions create corresponding differences in climate. Hence, certain parts of the world have been termed tropical because of the traits of the climate they exhibit.

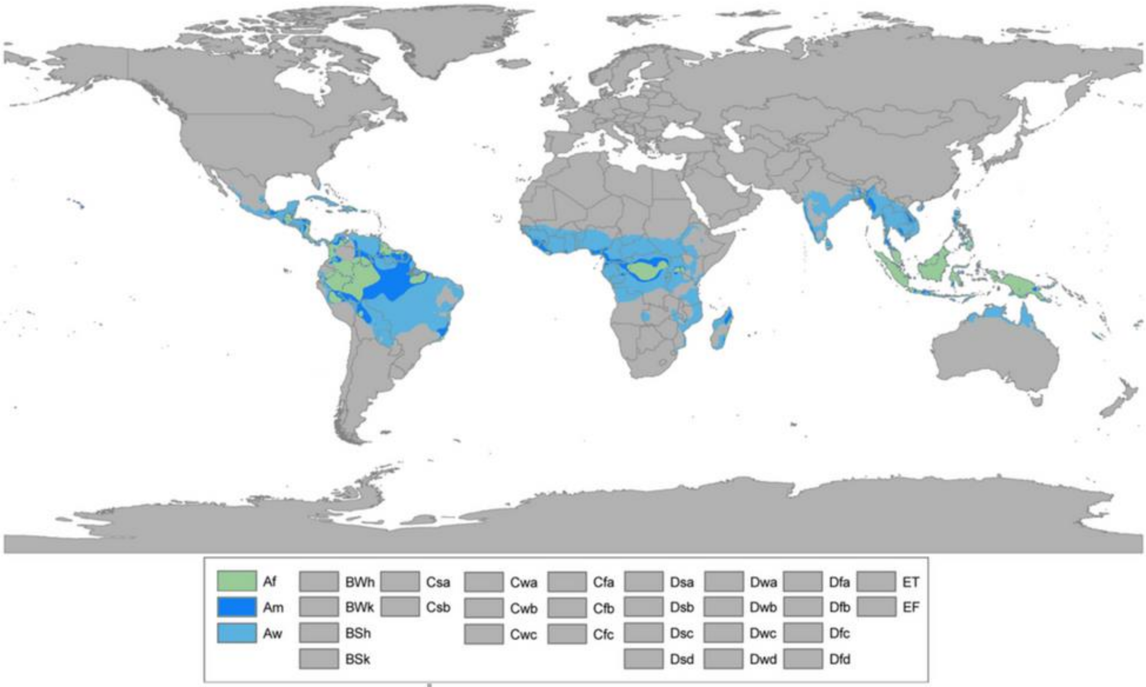
Much research has gone into understanding the peculiarities of the tropical climate that is mostly described as ‘hot’ and ‘humid’ in relation to other world climates. Tropical climates have come to be generally associated with world regions where the sun is directly overhead at least once a year (Olaniyan, Ayinla & Odetoye, 2013) (see Figure 2.15). Over the years, various classification systems have been employed in order to understand the tropical climate. The most popular tools that have surfaced in this regard are the Köppen-Geiger and Atkinson classification systems. The Köppen-Geiger classification is a typical tool for identifying world climates. The Köppen-Geiger climate model, which provides a detailed description of world climates, presents tropical climates as the type A climates - equatorial climates (Kottek, Grieser, Beck, Rudolf & Rubel, 2006). Hence, both terms – ‘equatorial’ and ‘tropical’ are used interchangeably. Another climate classification model is Atkinson’s 1953 model (Koenigsberger, et al., 1974). In research on thermal comfort, Atkinson’s climate classification has proved to be the most used and useful, as it is based on the two elements of thermal comfort – temperature and humidity. As, this study focuses on thermal comfort, Atkinson’s climatic classification system, as described by Koenigsberger et al. (1974), is used to examine the tropical climate.

Accordingly, tropical climates can be further organised into three climatic zones and sub-climatic zones, based on differences in geography:

1a. Warm-humid equatorial climate

These climates are found within 15°N and S of the equator (Jamaludin, Khamidi, Wahab & Klufallah, 2014). They are also referred to as ‘hot-humid’, ‘warm-humid’ or ‘tropical rainforest’ or simply ‘tropical’ climates. Seasons typically remain the same all-year round, apart from differences in the amount of rainfall during certain periods – more rain in the wetter months and less rain in the drier months. Precipitation is high, with an annual measure of 2000mm to 5000mm, and 550mm in the wettest month (Koenigsberger et al, 1974; Salmon, 1999). The areas with this climate often experience thunderstorms with strong winds and atmospheric electrical discharges (Fry & Drew, 1964; Koenigsberger et al, 1974). However, wind speeds are generally low, apart from the strong winds that would accompany the occasional thunderstorm. The average maximum daytime air temperature ranges between 27°C and 32°C while night time temperature is between 21° to 27°C. hence, diurnal ranges are very low and temperatures remain fairly constant all year round.

Humidity levels are generally high throughout the year, with an average of 75% and a range of 55% and 100%. The skies are usually cloudy throughout the year with a cloud cover range of between 60% to 90%; still bright skies are seen when the clouds are thin or the sun shines through (Fry & Drew, 1964).



Koppen	Atkinson
Af	Warm-humid equatorial climate
Am	Composite or monsoon climate
Aw	Hot-dry desert /Semi-desert climate

Figure 2.15 Köppen's world tropical climates classification, corresponding with Atkinson's world tropical climates classification; source: adapted from Peel, Finlayson & McMahon (2007).

Due to the general cloudiness and high levels of atmospheric water vapour caused by high humidity, the solar radiation is diluted but strong. In addition, the radiation absorbed by the ground and sea is prevented from dissipating due to the thick cloud cover and high vapour content, contributing to the torrid air temperature. Due to the constant rain, high humidity and temperature, vegetative cover is very thick and "*organic building materials tend to decay rapidly*" (Koenigsberger et al, 1974, p.26).

Locations that display this climate include Lagos, Nigeria; Dar-es-Salaam, Tanzania; Singapore; Jakarta, Indonesia among others.

1b. Warm-humid island or trade-wind climate

This climate type is exhibited by islands in the equatorial region, hence the climate bears a lot of similarity to the warm-humid equatorial climate. The average diurnal air temperature range is 29°C to 32°C and humidity is high (between 55% and 100%). Precipitation levels are lower in this climate than in the warm-humid equatorial one, with annual measures of 1250 to 1800 mm. The skies are usually clear, encouraging strong and direct solar radiation. Steady trade winds help to provide relief from high temperatures and humidity; however, cyclones and hurricanes are accompanied by stronger winds and can be dangerous. Vegetative cover is not as thick as that of the warm-humid equatorial climate.

Places that have the warm-humid island climate include the Pacific islands: The Philippines, the Caribbean and so on.

2a. Hot-dry desert, semi-desert climate

These climates are found in regions, 15°N and 30°S of the equator. The climate is characterised by a hotter season and a cooler one. During the hot season, extreme temperatures surface with a diurnal day-time maximum range of 43° to 49°C, and night-time minimum range of 24° to 30°C. in the cool season, the daytime maximum air temperature ranges between 27°C and 32°C degrees and at night 10°C to 18°C. Hence the diurnal range is large. Annual rainfall is light but is subject to variation when for instance, flash storms occur; humidity levels are correspondingly low, with a relative humidity range of 10% to 55%. Subsequently, soil is very hot and dry causing scant vegetative cover. Low humidity also contributes to the low cloud cover, which produces clear skies and cold nights as heat is easily radiated back to the sky. Furthermore, clear skies facilitate strong and direct solar radiation, heating up the ground surface during the day. Local hot winds cause whirlwinds due to temperature inversion (as the air closer to the hot ground is warm and the air higher up is cool), and carry dust and sand, causing sandstorms.

The hot-dry desert, semi-desert climate is found in places such as Arizona, Tucson, Baghdad, Peru, Alice Springs, Ethiopia and Namibia among others.

2b. Hot-dry maritime climate

In the words of Koenigsberger et al., (1974, p.28) "*maritime desert climates occur in the same latitude belts as the hot-dry climates, where the sea adjoins a large land mass…*", are "*amongst the most unfavourable climates of the earth*" and can be found in places such as "…*Kuwait, Antofagasta and Karachi*…". Just like the hot-dry desert climates, the maritime climate has a hot season and a cool season. During the hot season, the daytime temperature is an average of 38°C and the minimum night time temperature range is between 24°C and 30°C. On the other hand, maximum day time temperatures remain between 21°C and 26°C while minimum night time temperatures range between 10°C and 18°C in the cool season. Relative humidity levels are constantly elevated (between 50%-90%). Moreover, strong and direct solar radiation causes evaporation from the sea; hence the amount of water vapour in the atmosphere is immense. Unfortunately, the humidity does not dissipate, causing extreme discomfort. Cloud cover, rainfall and solar radiation levels, and vegetative cover are very similar to those of the hot-dry climates. Local winds are coastal, featuring land and sea breezes, dust- and sand-storms.

3a. Composite or monsoon climate

This climate is found in areas farther away from the equator and closer to the Tropics of Cancer and Capricorn. Therefore, the climate displays a mix of hot-dry and warm-humid climatic features, creating a longer hot-dry season and a shorter warm-humid season in a typical year. However, in the northern and southern regions exhibiting this climate, there is a third season known as the cool-dry season. The daytime maximum temperature during the hot-dry season is 32°C to 43°C, while the night time temperature is between 21°C and 27°C. As for the warm-humid period, temperatures are slightly lower with a maximum day time temperature range of 27°C to 32°C and a minimum night time range of 24°C to 27°C. Temperatures are lowest in the third season and maximum day time temperatures do not go above 27°C, and night time range of 4°C to 10°C. Precipitation levels are high with excessive monsoon rains; however, humidity levels are relatively low, at 20 to 55% during the dry seasons and 55 to 95% during the humid season. As such, vegetation is bountiful during the warm-humid season when there is a lot of rain and sparse when the hot-dry season comes up. The sky conditions and solar radiation depend on the season; generally, skies are clearer and solar radiation more intense during the hot-dry season than during the warm-humid season when the monsoon rains are accompanied by cloudy skies. The nature of the winds varies with the season; hot, dusty winds occur during the dry season while strong, wet winds come during the humid season.

3b. Tropical upland climate

This climate is found in regions on mountains and plateaux. The annual air temperature range varies according to the latitude of the location. In addition, latitude affects the type of radiation emitted as ultra-violet radiation is more intense at lower latitudes. In addition, temperatures in the shade, decrease with increase in altitude, where temperatures can get as low as 4°C at night. However, at an altitude of 1800 m, the maximum day time air temperature is between 24°C to 30°C while the night time minimum temperature range is 10 to 13°C. Rainfall levels vary but are generally high while humidity levels exhibit a similar variableness, ranging between 45% and 99%. Skies are usually clear or partially overcast but are darkest during the monsoon rains. The solar radiation is strong when there are clear skies but diffuses when the sky clouds over.

Table 2.2 The variants of global tropical climates.

Label			Climate		
Zone	**Sub-zone**	**Location**	**Annual Temp. range (°C)**	**Annual Rain. range (mm)**	**Annual Humidity (%)**
Warm-humid equatorial	-	15°N and S of equator	21 – 32	2000 – 5000	55 – 100
	Warm-humid Island/Trade-wind		21 – 32	1250 – 1800	55 – 100
Hot-dry desert, Semi-desert	-	15°N and 30°S of equator	10 – 49	Light	10 – 55
	Hot-dry maritime		10 – 30	Light	50 – 90
Composite/ Monsoon climate	-	Close to the Tropics of Cancer & Capricorn	4 - 43	High	20 - 95
	Tropical upland	Mountains and plateaux	4 - 30	High	45 - 95

Source: author's study.

An overview of the climate types that constitute the tropical climate shows that the general characteristics of the tropics are seasons defined by high humidity, high solar radiation and subsequently, high temperatures (Olaniyan, Ayinla & Odetoye, 2013) (see Table 2.2). These definitions connote a particular need: cooling and dehumidification, for the people who live in tropical regions. Koenigsberger et al. (1974, p.3) say that "…*Tropical climates are those where heat is the dominant problem, where, for the greater part of the year, buildings serve to keep the occupants cool, rather than warm, where the annual mean temperature is not less than 20°C…*" Therefore, the striking characteristics of the tropical climate greatly impact the built environment, including housing. At this point, it is important to indicate that the specific climatic context of this study is the warm-humid equatorial climate, where the general needs of the tropics as described above, are more weighty than other sub-tropical zones (Koenigsberger et al, 1974). Housing in the warm-humid tropics is an eclectic subject, exhibiting different themes apart from the present focus on its contextual climatic influences (Karol & Chin Lai, 2014).

2.5 Housing where it's warm and humid – how, when and why?

Housing in the warm-humid tropics has become a major subject associated with climatic design (Ibid). The uniqueness of the tropical thermal environment has provided a challenge that has become a jumping-off point for the generation of ideas in climatic design. Although the climatic element is very prominent when tropical housing is discussed, it can be inferred from Fry & Drew (1964) and Salmon (1999) that tropical housing can be viewed from three different perspectives: the people and their needs, materials and construction and climatic impacts. These perspectives seem to correspond with the three dimensions of sustainability (see Figure 2.26). As such, housing responses may be classed under these three categories. Hence the way the people of the warm-humid tropics responded to their need for shelter can be analysed from these three points. Studies have revealed that the socio-cultural and economic scopes of tropical housing embody responses to climate in many ways (Moriarty, 1980; Osasona, 2007a, Butera, Aste & Adhikari, 2014). Furthermore, Salmon (1999) inspires the notion that tropical housing can be further comprehended based on chronological changes. Cenicacelaya & Baganha (2004), Prianto, Bonneaud, Depecker & Peneau (2000) provoke thoughts that the advent of technology and westernisation created a chronological classification by which tropical housing may be referred to as 'traditional', 'colonial/transitional' and 'contemporary'. The following critiques on warm-humid tropical housing will be based on the sustainability-time premise, earlier discussed (see summary in Table 2.3).

2.5.1 Returning to the past - Traditional housing responses in the warm-humid equatorial tropics

In the case of housing, the terms 'traditional' and 'vernacular' are used interchangeably. Both terms connote a concept that is specifically linked to the indigenous culture of a region, community or class (McArthur, 2003; Hourigan, 2015). Still, Osasona (2007a, p.6) argues that the vernacular connotes "*a brand of architecture resulting from the traditional being conditioned by external forces*"; as such it is "*post-traditional…having evolved from a process of selective borrowing*…" This assertion can be criticised as the concept of 'vernacular' has become generally associated with historic settings (Cenicacelaya and Baganha, 2004; Jamaludin, et al, 2014). Still traditional housing is more popularly used to refer to indigenous housing that "*suits local…climates and is a reflection of the customs and surrounding landscape of a community*" (Shaw, Colley & Connell, 2007, p.9). Chronologically, traditional housing is associated with "*rural buildings of the preindustrial era*" (Hourigan, 2015, p.24), and "*the first advances of civilisation*" (ibid., p.22) in a certain region. Considering this, traditional housing in the warm-humid equatorial regions demonstrates the response to the tropical socio-economic and environmental milieu in many specific ways.

Socio-culturally, traditional housing responses in the warm-humid tropics, are shown in building form, typology, space provision and syntax. These responses were influenced by mundane activities, family systems, societal norms and religious beliefs (Moriarty, 1980; Prianto et al., 2000; Jamaludin, et al, 2014). Housing practices based on these influences produced dwellings that ensured the well-being of the occupants, while exhibiting potential for adaptation. It may be said that the basic house type in these settlements was a detached, multi-functional living space/apartment, which corresponds with the bungalow type (Fry & Drew, 1964). Compound dwellings with groups of one to two room apartments were well-known in certain cultures where a family would consist of a man, two or more wives and children, as well as extended family members. Doors and windows were usually narrow and made of wood; windows were usually constructed in casement fashion and fully openable (Osasona, 2007a, Jiboye & Ogunshakin, 2010, Prianto et al, 2000; Kamal, Wahab & Ahmad, 2004). Building utilities were absent in the traditional dwelling (Prianto et al, 2000); so, houses were free-running – devoid of any active heating or cooling (Nicol, 2004). Water would be sourced from wells, rivers and streams while sources of lighting were natural daylight in the daytime and local lamps, fires in hearths, and moonlight at night (Atkinson, 1950; Karol & Chin Lai, 2014).

For many traditional warm-humid tropical dwellings, space provision and syntax were influenced by the number of people in families, nature of daily activities, religious beliefs and societal norms (Prianto et al., 2000). For example, traditional housing associated with the Igbo tribes of South-Eastern Nigeria exhibited rooms organised per the rank of the family members with respect to the family head (Osasona, 2007a). Consequently, domestic spaces for sleeping were essential to the spatial configuration of the one-storey, low-ceiling houses while the communal (cooking, laundry and meeting) spaces were attached to the basic sleeping units. The sleeping areas were the most protected as valuables were also stored therein (Jiboye & Ogunshakin, 2010). The space syntax eased the addition of rooms if required (Danby, 1971). Toilets and bathrooms were separate from the main areas (Moriarty, 1980). Furthermore, typical dwellings in the hot/warm-humid climates show large outdoor/semi-outdoor spaces such as the courtyard where activities such as social gatherings, cooking and laundry take place (Butera, Adhikari & Aste, 2014). Outdoor cooking was a relevant social activity especially among the women. However, it has been said to pose health concerns as fire for cooking was generated through the burning of biomass, generating fire and releasing smoke which endangers health and life (International Energy Agency, 2012; Atkinson, 1950). Still, outdoor living was mundane in these parts, as natives of the hot-humid regions held agrarian occupations, working outdoors for most of the day and retiring at night for mainly different forms of social engagement and sleep (Butera, Adhikari & Aste, 2014). The houses in the Gezira, as well as West African houses feature the use of courtyards (Moriarty, 1980; Osasona, 2007a).

Figure 2.16 Traditional house of the Hausa (northern Nigeria) built in typical indigenous materials (mud and timber); source: Osasona (2015, p.43).

The cultural aesthetics were modelled in building forms and elements. Traditional houses in the tropics were indicative of basic shapes: triangle -for example, the tent-like structures of the Sudanese nomads, rectangle – for example, the Malay house, and circle- for example, the earlier houses of the Sudanese nomads (Danby, 1971; Moughtin, 1964; Shaw, Colley & Connell, 2009). Some other dwellings would exhibit decorative detailing in building elements such as door frames, columns, wall and so on. These embellishments would sometimes portray folklore, spiritual concepts and so on (Tamjidi & Bozorgvar, 2015; Osasona, 2007b). Furthermore, much interest has been expressed interest in the way these socio-cultural components of tropical vernacular housing were expressed using local materials and construction.

The most common materials used for traditional house construction in these parts include: adobe, timber, bamboo for walls; for roofs: timber, thatch, mud, bamboo and floors: earth, clay (Atkinson 1950; Alcock, 1969; Bodach, Lang & Hamhaber, 2014) (see Figure 2.16). Supplementary materials included straw, animal dung for plastering walls among others (Hammond, 1973). Construction costs in these settings have been termed ‘affordable’, ‘cost-effective’ and so on (Butera, Adhikari & Aste, 2014). The fact that materials are locally sourced and labour includes members of community, is the reason for low construction costs in tropical traditional house construction (Moriarty, 1980). The common practice in many warm-humid equatorial indigenous communities was: when a member of the locality wanted to build a house, he and his kinsmen would be the labour (Atkinson, 1950). However, issues of high maintenance costs, low durability and health hazards linked to the use of traditional materials (Karol & Chin Lai, 2014; Moriarty, 1980) have been discovered. Noteworthy is the management of space associated with the warm-humid equatorial traditional house types. Moriarty (1980) implies that the spread-out nature and openness of the tropical traditional house-type would find difficulty thriving in urban areas and imply more expenditure on construction materials.

In the warm-humid equatorial climate, where high rainfall is a definite feature, moisture affects these materials. Reports exist on the tendency for mud walls to be washed away by floods, wood and bamboo elements prone to rot due to high humidity levels and so on (Danby, 1971; Fry & Drew, 1964). Even more, Fry & Drew (1964) explain that thatch deteriorates after 18 months and is highly flammable. Still, thatch roofs have been praised for being noise-combatant in a climate where heavy rains are frequent and the sound of raindrops on the roof can be a disturbance (Moriarty, 1980; Kamal, Wahab & Ahmad, 2004). Accordingly, if the buildings built in these materials must perform well, there is a demand for commitment to continual maintenance. However, Karol & Chin Lai (2014) make a valid point by indicating that in current society, less time is available to maintain houses constructed from local materials. Still, authors such as Alcock (1969) and Hammond (1973) refer to Peruvian and Nigerian indigenous houses that have stood the test of time, to demonstrate that sustaining traditional construction is possible and rewarding. Nevertheless, it seems that researchers make the strongest case for traditional building materials in the tropics, with regards to their suitability to the tropical environment.

The appropriateness of warm-humid equatorial indigenous materials and construction to their contextual surroundings, has been lauded by many studies (Bodach, Lang & Hamhaber, 2014). This appropriateness is seen in the relationship between the materials, construction and the warm-humid equatorial climate (Kamal, Wahab and Ahmad, 2004). A lot has been said on the impressive thermal properties of vernacular earthen walls in these climates (Ali, Alamoudi, Alajmi, Khayat & Alshraim, 2014; Salmon, 1999). Traditional dwellings with earth walls have been found to be cooler during the hot days, as they absorb heat slowly, and warmer during the cooler nights, when they give off the absorbed heat. Furthermore, the traditional thatch roof, despite being highly flammable and disposed to be a health hazard (Fry & Drew, 1964), is praised for being cool, quiet and able to last for up to 40 years. Roofs were usually pitched with

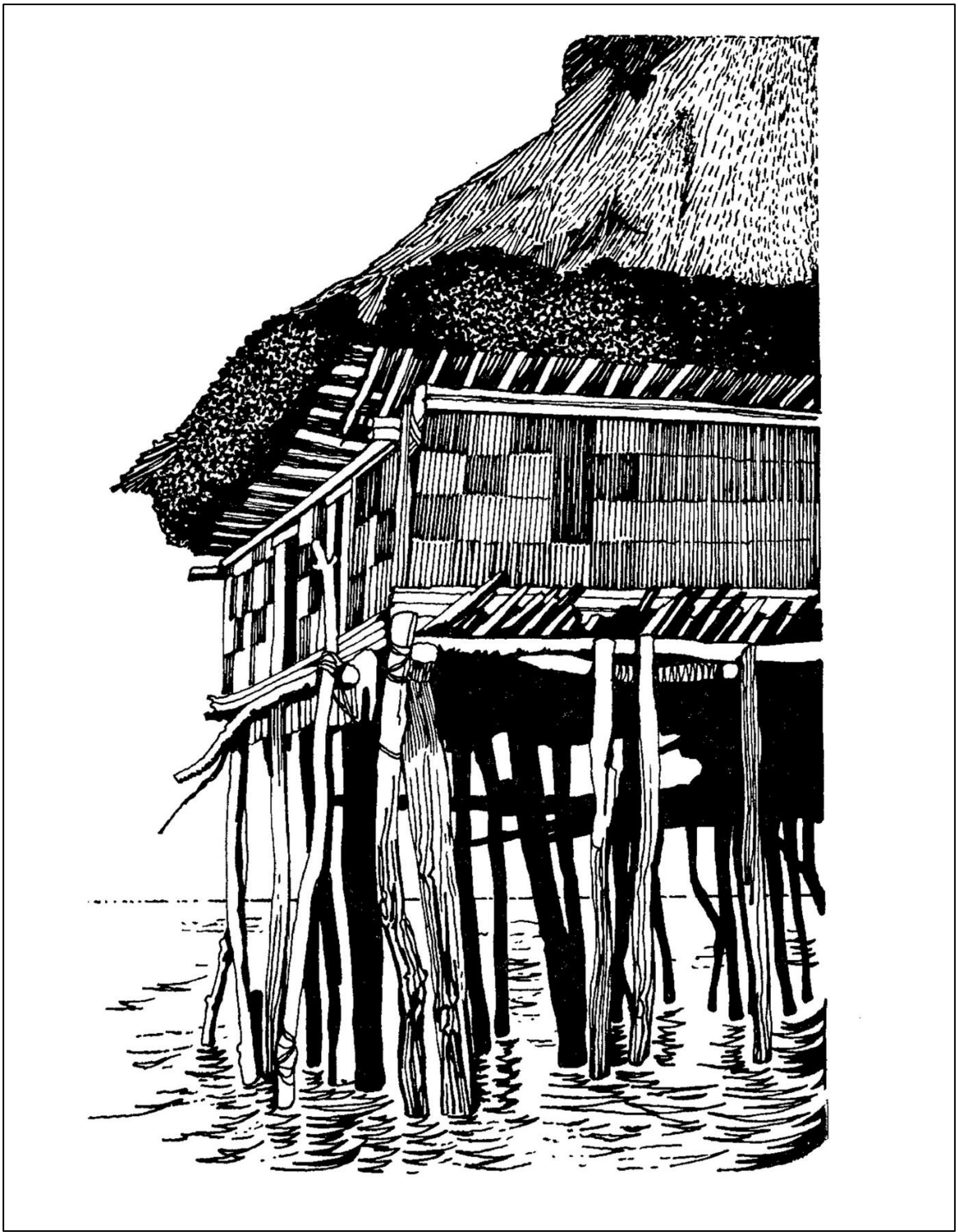


Figure 2.17 A variant of traditional tropical housing – stilted lake house in Ganvié, Dahomey; source: Danby (1971, p.13).

large overhangs in response to warm-humid equatorial heavy rains. The pitched roofs facilitated air circulation, aiding in thermal control. However, in sub-tropical zones where rainfall is less than rainforest zones, flat roofs were employed. Examples include the vernacular housing of the older Sudanese tribes around the Nile, and of the Northern Nigerian tribes among others (Danby, 1971; Moughtin, 1964).

Apart from the material-construction-climate response, there is also the building form-topography response. Interestingly, the building form-topography response also facilitated the comfortable indoor thermal environments of the tropical vernacular house (Salmon, 1999). One variant is the tropical riverine house which was built of timber walls, on stilts above water (see Figure 2.17); examples are the traditional lake houses of ancient Dahomey (West Africa) (Danby, 1971), traditional Sama house of the Philippines (Nimmo, 1990) and traditional Malay house (Kamal, Wahab & Ahmad, 2004). On the other hand, some early west African indigenous houses were also stilted houses. The raised structures were better ventilated and cooler as they caught cooler breezes flowing higher up, were distanced from ground radiation and took advantage of cooler night temperatures (Fry & Drew, 1964). A few studies have praised timber walls for facilitating thermal comfort as they are lightweight with low thermal capacity, absorbing little heat (Kamal, Wahab & Ahmad, 2004; O'Brien, 2006). However, this claim has been questioned by many more researchers who defend high thermal mass as seen in traditional earthen walls (Salmon, 1999; Ali, et al, 2014).

At this point, the link between space morphology and climate is relevant. The courtyard has become a symbol of the climate-responsive of tropical traditional housing (Ali et al, 2014; Butera, Aste & Adhikari, 2014). As discussed earlier, the courtyard was usually a multi-functional space, around which other spaces were situated (Atkinson, 1950). The courtyard promoted good ventilation and cooling as it was open to the environment with a good height for the stack effect (Danby, 1971). Still, the activities that took place in the courtyard have been criticised. Outdoor cooking by burning biomass has been said to contribute to climate change (International Energy Agency, 2012), a global environmental concern to be discussed later. Furthermore, Moriarty (1980); Kamal, Wahab and Ahmed (2004) mention that the popular traditional house-form of a residential compound containing multiple buildings as well as the openness of the building envelope, encouraged maximum ventilation and daylighting.

Thus, the indigenous housing of the warm-humid equatorial regions demonstrated didactic techniques in the several ways the people and their needs, environment and economy were consolidated into the housing process. Consequently, there is a prevailing emphasis on learning from the past in this premise. However, as time has passed, external cultural influences have caused modifications to tropical housing forms.

2.5.2 Transitioning – colonial housing responses in warm-humid equatorial climates

The spread of European governance was the catalyst for the changes that tropical traditional housing experienced (Moriarty, 1980; Kamal, Wahab & Ahmad, 2004). The era of colonialism can be placed between the mid-nineteenth century and 1960 (Havinden & Meredith, 1997). With a great amount of British influence, came several changes to the culture and settlement patterns of indigenous tropical cultures (Uduku, 2006). According to Drew (1974), the British Government passed the Colonial Development and Welfare Act which fostered the physical development and planning of its colonies. Distinctions between rural, sub-urban and urban settlements developed as the British government created townships in these regions. European settlers lived in isolated bungalows, away from the indigenous houses (Ibid). These bungalows were surrounded by large expanses of land which served as gardens, polo fields and race courses. The Europeans lived away from the indigenes to avoid contractible diseases. Indigenes migrated from original villages and hamlets into the new towns, in search of employment (Atkinson, 1950). The colonial government set up housing schemes to shelter the immigrants. These schemes can be said to be the foundation of the tropical modern mass housing projects (ibid.), which will be discussed later. However, many of these schemes were sub-standard when compared to the housing of government officials and the elite. The typical house type of this time was the bungalow once again, although now embellished by many borrowed elements. Terrace and semi-detached bungalows became popular and so did, multiple-storey houses, where detached, one-storey folk houses had been the norm (Ibid; Prianto et al, 2000).

In terms of space morphology, the colonial house types, under western (mostly European) effect, had all the spaces under one roof, as opposed to the traditional layout of dispersed spaces within a major area (Moriarty, 1980). Toilets and kitchens-which were usually separated from the communal spaces in the tropical traditional house-were combined with the latter in the colonial houses. Moriarty (1980) indicates that the disconnected kitchens of the traditional, were safer as the fire and heat could not affect other parts of the house. Still, the modern kitchens were fitted with safer cooking devices such as kerosene and gas stoves (International Energy Agency, 2011). Ceilings became higher; the number and sizes of doors and windows in the building envelope increased (Prianto et al, 2000). Although the folk courtyard space became less common, verandas and corridors through and around living spaces became very popular features of the tropical colonial house-types (Atkinson, 1950) (see Figure 2.18). The individual units such as a living area, kitchen, store, bedrooms, and convenience opened into a central circulation space such as a corridor or veranda. The private bedroom and convenience spaces were closer to the posterior veranda than the other spaces. In west African regions, some versions of the colonial house would display understated "*mural mouldings at eaves and plinths; also on column capitals and balustrades*" (Osasona, 2007a, 10). Yet, the basic colonial house types in the warm-humid regions have been praised for adaptability. The simplicity of the general space morphology of the houses, made it possible for future conversion into shops and other related functions (Osasona, 2007a; Danby, 1971).

The initial versions of the colonial house types (which were more flamboyant than the common typology described above) were built for the government officials and few indigenes who had accumulated wealth in the new society (King, 1984; Uduku, 2006). These houses showcased the experimental nature of colonial design and a marriage of indigenous and European architecture (Prucnal-Ogunsote, 1993; Prianto et al, 2000; Uduku, 2006). It was at this point that housing became a strong indicator of socio-economic status in these parts. Socially, these changes were welcome as proof of improved living (Danby, 1971). Hence, many low-middle income indigenes-especially migrants from rural areas- made efforts to replicate the basic colonial house type, despite inadequate funds (Immerwahr, 2007). The results were sub-standard versions that degenerated into informal settlement clusters. The UN-Habitat (2015, p.1) defines informal settlements as "…*residential areas where 1) inhabitants have no security of tenure vis-à-vis the land or dwellings they inhabit, with modalities ranging from squatting to informal rental housing, 2) the neighbourhoods usually lack, or are cut off from, basic services and city infrastructure and 3) the housing may not comply with current planning and building regulations, and is often situated in geographically and environmentally hazardous areas*…" Accordingly, the earlier-mentioned mass

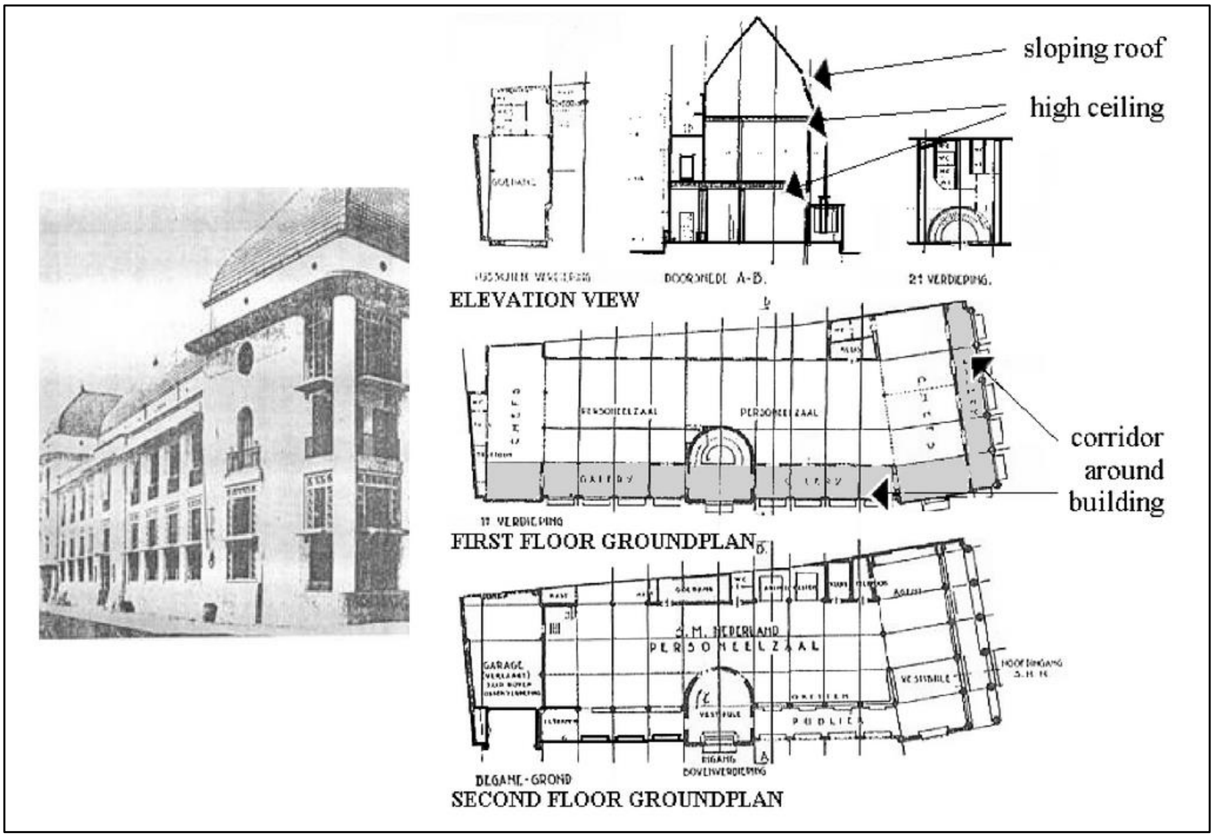


Figure 2.18 Colonial housing in Semarang, Java Island (floor plans show corridor feature); source: Prianto et al (2000, p.84).

housing schemes were designed by the government to accommodate indigenes who had to be moved from the informal settlements, to create space for infrastructural development (Uduku, 2006; Danby, 1971). High-rise apartment buildings were built with low ceilings, modern kitchens and balconies which had to be altered later to suit the occupants who still held on to traditional lifestyles (Uduku, 2006). Hence, it is the mass housing schemes that have been most criticised than other forms of colonial housing in the warm/hot-humid regions. Common objections include unsuitability of the apartment buildings to family culture, health hazards due to overcrowding and difficulty in adapting the buildings to future functional changes (Moriarty, 1980). This has been said especially of the apartment buildings in the hot-humid regions of Africa and Asia (Danby, 1971).

With colonial housing came the advent of electricity supply in housing in the warm-humid equatorial regions. At this time, electricity was generated by burning coal (Mavhunga & Trischler, 2014/5). The high-class colonial houses were fitted with fans and air conditioning powered by electricity, to alleviate the heat of the climates (Danby, 1971; Uduku, 2006). Lighting and household appliances (which also ran on electricity) became a feature of these new builds as this was part of housing provision in the home countries of the settlers (Prianto et al, 2000). Mechanical domestic water systems were installed as modern kitchens and lavatories were imported into the colonial houses. Cooling devices such as fans were especially needed to assuage thermal discomfort in the mass housing flats. Karol & Chin Lai (2014) remark on the hazards of installing ceiling fans on low ceilings, but this was usual practice in these apartment blocks. Furthermore, the low ceilings did not allow for adequate air circulation and increased the likelihood of respiratory issues for occupants (Butera, Adhikari & Aste, 2014). These developments revealed a lifestyle that indigenes labelled ‘comfortable’ and associated with wealth and township living (Alcock, 1969). These new societal values inspired by colonial housing, became a motivator for rural-urban migration. However, the addition of these utilities also contributed to the cost of colonial housing (Atkinson, 1950).

Colonial construction in the warm-humid regions facilitated the introduction of imported materials. Walls were built in cement/concrete bricks, with glass-louvered windows; roofs in metal (zinc, corrugated iron) sheets and asbestos; floors in cement (Moriarty, 1980; Kamal, Wahab and Ahmad, 2004; Prianto et al, 2000; Alcock, 1969). The results were higher costs of construction and houses with more solid character than their traditional predecessors. Some of these modern materials such asbestos, have been found to pose health threats (Doll & Peto, 1985). Authors have placed much attention on the expenditure on the manufacture of borrowed construction and skill-cement/concrete production in these regions that did not originally produce them (Danby, 1971). Danby (1971) especially hints on the strangeness on the colonial need for skilled labour as opposed to the communal building system of the vernacular. Still, Atkinson (1950) remarks on the permanence of the western materials over the low durability of the traditional ones while Karol & Chin Lai (2014) state another advantage of western construction over traditional: less maintenance costs. However, Moriarty (1980) maintains that the lifetime costs of this new construction favoured only the wealthy minority. His study further indicates that during this period, housing construction became more commercial. With new building materials and techniques, skilled labour was required. In many hot-humid regions, foreign architects worked on housing the elite and government employees in the colonial towns (ibid); in West Africa, housing for low-middle income earners was achieved by the know-how of the indigenous descendants of returned slaves (Prucnal-Ogunsote, 1993). The self-build tradition of folk housing remained in the original rural settings.

Despite the introduction of these western materials, the colonial house-types demonstrated a subtle hold on some traditional values (Osasona, 2007a). Hence, there was a mix of indigenous and western building materials which produced colonial dwelling variant, especially common in native settlements being transitioned into urban centres (Atkinson, 1950). A specific example is the cement-stabilised earth block, whose earliest experiments were launched in colonial Ghana. The block was acclaimed for improved strength over the traditional earth block (Ibid; Alcock, 1969). Notwithstanding, even the colonial building materials suffered the harshness of the warm-humid equatorial climate. Painted walls easily acquired mould due to the excessive humidity levels (Uduku, 2006). This also indicated the climate-responsiveness of colonial housing in the warm-humid regions, which has, mostly, been thrown into positive light. Verandas and corridors of the basic colonial type-which replaced the traditional courtyard space-and larger fenestrations, encouraged cross ventilation and cooling. The elite types were famous for natural cooling as their design promoted air flow through and under the structure (Uduku, 2006) and the stack effect under high ceilings (Prianto et al, 2000) (see Figure 2.18). The form-climate response of the colonial house types was generally positive. More contention arises when the material-climate response is examined. The introduction of metal roofs into this climate has been heavily frowned upon, as metal is a taken-for-granted conductor of heat (Alcock, 1969). Many studies have linked this to reports of higher temperatures in these 'improved' houses than in the traditional dwellings. However, the higher pitch of these roofs created roof spaces that encouraged the stack effect in the basic colonial house. The use of concrete for wall construction has been criticised on grounds of cost; however, it has been praised for its thermal properties which promote good thermal control. Reflective wall finishes aided in the cooling effect of the walls, as they were painted in light colours (Uduku, 2006). Another way colonial housing in the warm-humid equatorial regions responded to climate was the incorporation of household appliances and cooling devices such as fans and air conditioning. However, these artificial thermal controls were introduced towards the end of the colonial period. This has been evidently frowned upon as the sources of power for these appliances, have been linked to climate change (Thiele, 2013; Adunola, 2014). Nevertheless, it seems that it was in the colonial era that there were real possibilities of developing a house model most adapted to socio-economic and environmental contexts in the warm-humid equatorial regions, which could also fit into the concept of 'modern society' (Uduku, 2006). However, this possibility, though realised for a notable period, is short-lived, due to the accompanying economic investments (ibid.)

Osasona (2007a) and Prucnal-Ogunsote (1993) would argue that the emergence of the colonial houses exhibited a blend of Western and tropical indigenous values, created a distinct style which can be termed 'vernacular'. This school of thought maintains that external influences have been evaluated through time; more appropriate external influences were incorporated into the traditional housing system, resulting in an evolved model suitable for modern living in the tropical climate. Prianto et al, (2000) have identified this housing style and termed it 'colonial'. Authors like Uduku (2006) have termed this typology 'tropical'. These studies suggest that these foreign influences improved housing in the tropics. For instance, durable western materials, larger doors and windows, high roofs and ceilings married with the climate-responsive traditional space syntax created this improved style suited to its climatic context. However, other authors on this subject seem to favour a clear analysis of tropical housing into 'traditional' and 'modern', the modern category constituting the colonial types (Cenicacelaya & Baganha, 2004; Jamaludin et al, 2014; Bodach, Lang and Hamhaber, 2014). Thus, it can be said the beginnings of the modern housing evolution in the warm-humid regions began with the introduction of the colonial house types. Still, contemporary advancement has birthed more sophisticated housing than the housing of colonial times.

2.5.3 Trendy times - Contemporary housing responses in warm-humid equatorial climates

There is a general notoriety of contemporary housing in hot-humid climates that creates a readily-accepted bias when it is examined in the light of the people and their needs, economy and climate. However, this study looks at the evolution of contemporary housing in these regions, beyond the surface. First, the term 'contemporary' in architecture may be said to connote architecture associated with urban centres and post-modern cities of the 21st century (Cenicacelaya and Baganha, 2004). This ideal has its roots in modern architecture cultivated by western industrialisation, subsequent urbanisation and capitalism of the nineteenth century (Heynen, 1999). Modern architecture is synonymous with functionality and geometric structures; it symbolises technological, societal advancement, the leap into the future and "*attempts… to transcend the constraints of traditional forms*" (Salmon, 1999, p.87). Hence, modern functionality expressed in the angular and minimalist motifs of contemporary construction character, is opposed to the soft, ornamental, rhythmic traditional patterns. These modern ideals constitute modern housing forms. Modern housing was created to be avant-garde and functional; this was the expression in the west where the modern movement was birthed (Cenicacelaya and Baganha, 2004). On transfer to opposite regions of the world such as locations with hot-humid climates, there was an adjustment phase – the colonial housing era, where modern influences blended into indigenous housing and thus, were not as strong as they were at their points of origin. However, when these colonies obtained independence in the mid-late twentieth century, the indigenous governments began to model their policies on those of the West, to participate in the global idea of a futuristic world. It was then that the concept of modern broke through the balance of colonial housing. Traditional housing, though still seen if sought after, retreated into the background in the hot-humid regions (Salmon, 1999).

The prevailing influence, leading to the development of what has been termed contemporary housing in warm-humid equatorial regions, has been tied to the International Style (Uduku, 2006; Moriarty, 1980). Hence, modern housing in the hot-humid regions has grown beyond the initial Colonial housing responses into futuristic and commercial contemporary housing, heavily influenced by the International Style (Kamal, Wahab & Ahmad, 2004). Lifestyle changes have been immersed in urban development of these regions, many of which are classified as developing regions (Karol & Chin Lai, 2014). Furthermore, the distinctions between high-class, middle-class and low-class in these regions, have become more pronounced and shows through contemporary housing (Prucnal-Ogunsote, 1993). During the colonial era and 20th century, many natives were educated and exposed to Western family living (O'Brien, 2006). Hence, education and white-collar jobs in the cities now ruled by educated natives, redefined socio-cultural norms in these parts. The traditional agrarian occupations remain in the rural settlements. Accordingly, typical urban family house is based on the colonial bungalow: all spaces (Living room, kitchen, lavatory, and bedrooms) under one roof with a low ceiling, linked by corridors and lobbies. Even more the quadrangular from of the houses has been passed down through the traditional and Colonial (Philokyprou, 2014), while the less popular traditional spatial and structural forms (circular and triangular) have nearly faded out. However, the new space morphology does not favour adaptability the way the traditional and colonial versions did (Prianto et al, 2000). In addition, city jobs are better-paying and many middle-income earners presently house themselves, like the upper class have done since the colonial times, by seeking the services of architects and builders to construct bespoke detached bungalows with the space syntax described above (O'Brien, 2006; Osasona, 2007a). The houses of the rich are more flamboyant demonstrations of the International style; many are ornamental, multi-level, spacious-possessing multiple living rooms (commonly with high ceilings), kitchens, lavatories and bedrooms-with landscaped exteriors (Danby, 1971; Uduku, 2006) (see Figures 2.19, 2.20 and 2.21). Improved security measures are demonstrated in the design of contemporary houses; high fences, sometimes topped with broken glass or barbed wires, encompassed the contemporary high-class and middle class-home. This facilitates an individualistic and private urban lifestyle as opposed to the traditional communal culture (Karol & Chin Lai, 2014). The introduction of water supply and electrical systems also characterise contemporary housing; some authors would state that this provides improved levels of comfort and easy living (Tessema, Taipale & Bethge, 2009). The traditional way was to depend on daylighting, fires and lamps for lighting and the strenuous efforts of drawing water from wells, rivers and streams. This remains in many native settlements.

Figure 2.19 A contemporary tropical house at Kayangan Heights, Shah Alam, Malaysia, showing the ornamental variants of the International Style housing of the tropics, including multi-levels and high ceilings; source: Ahmad (2008, p.280 (left) and p.282 (right)).

Some sense of community is still portrayed in the mass housing schemes that the government and private contractors continue to set up, based on the Colonial pioneers (Atkinson, 1950) (Figure 2.22 shows colonial tenement housing in a tropical location). The newer models are being occupied by middle-income earners, usually civil servants, and still built with low ceilings, modern kitchens and balconies (see Figure 2.23). However, the Colonial examples in this era, have become derelict, occupied by low-income earners, earning such residential areas have become informal settlements. These low-income earners belong to the group that could start small business in the city as petty traders, artisans and so on (ibid). However, the deterioration of the Colonial mass housing schemes inspired new theories on self-help low cost housing (Alcock, 1969). Hence, this group of low-income earners have been encouraged to house

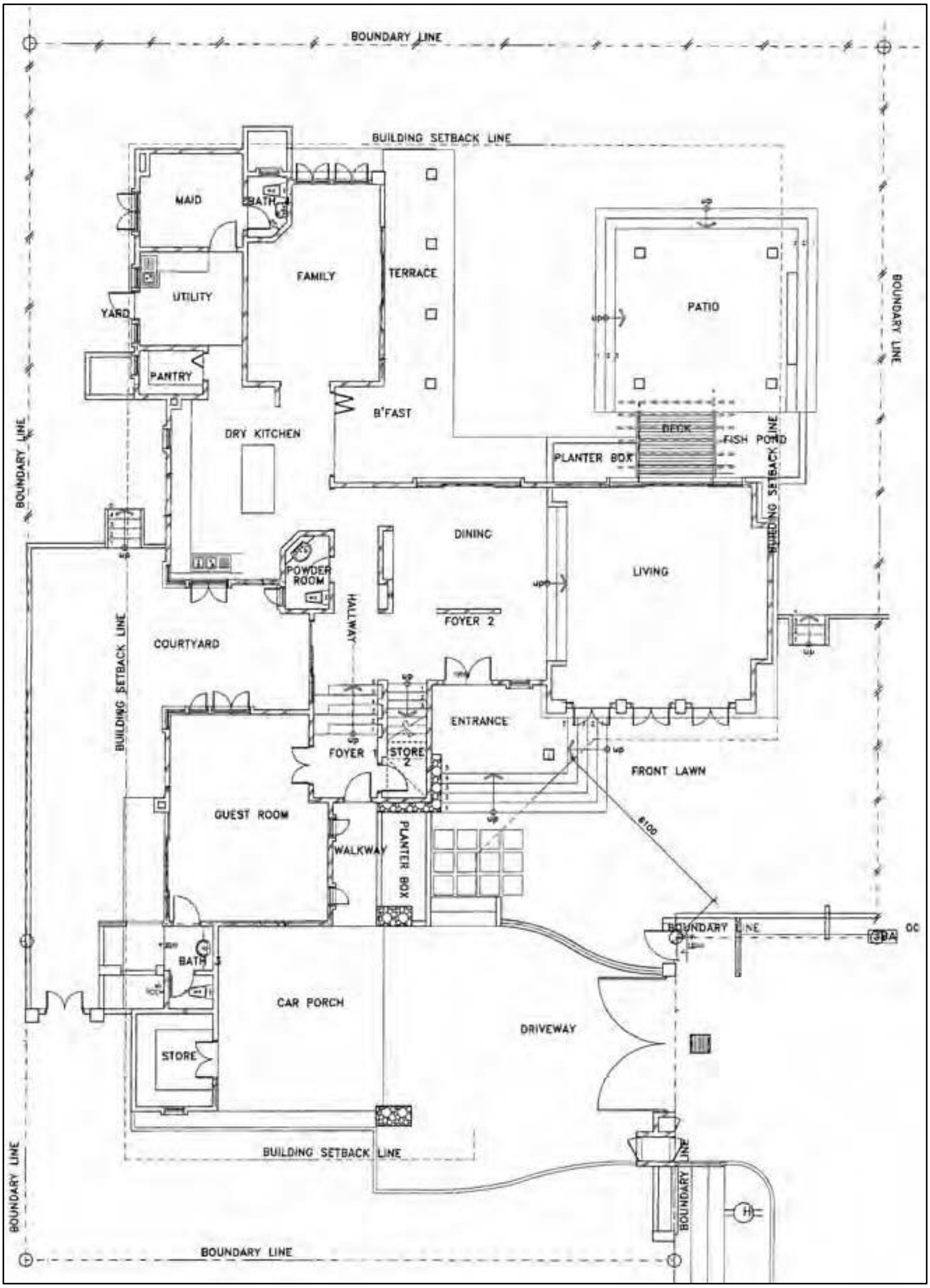


Figure 2.20 The ground floor plan of the contemporary tropical house at Kayangan Heights, Shah Alam, Malaysia, showing numerous functional spaces; source: Ahmad (2008, p.286).

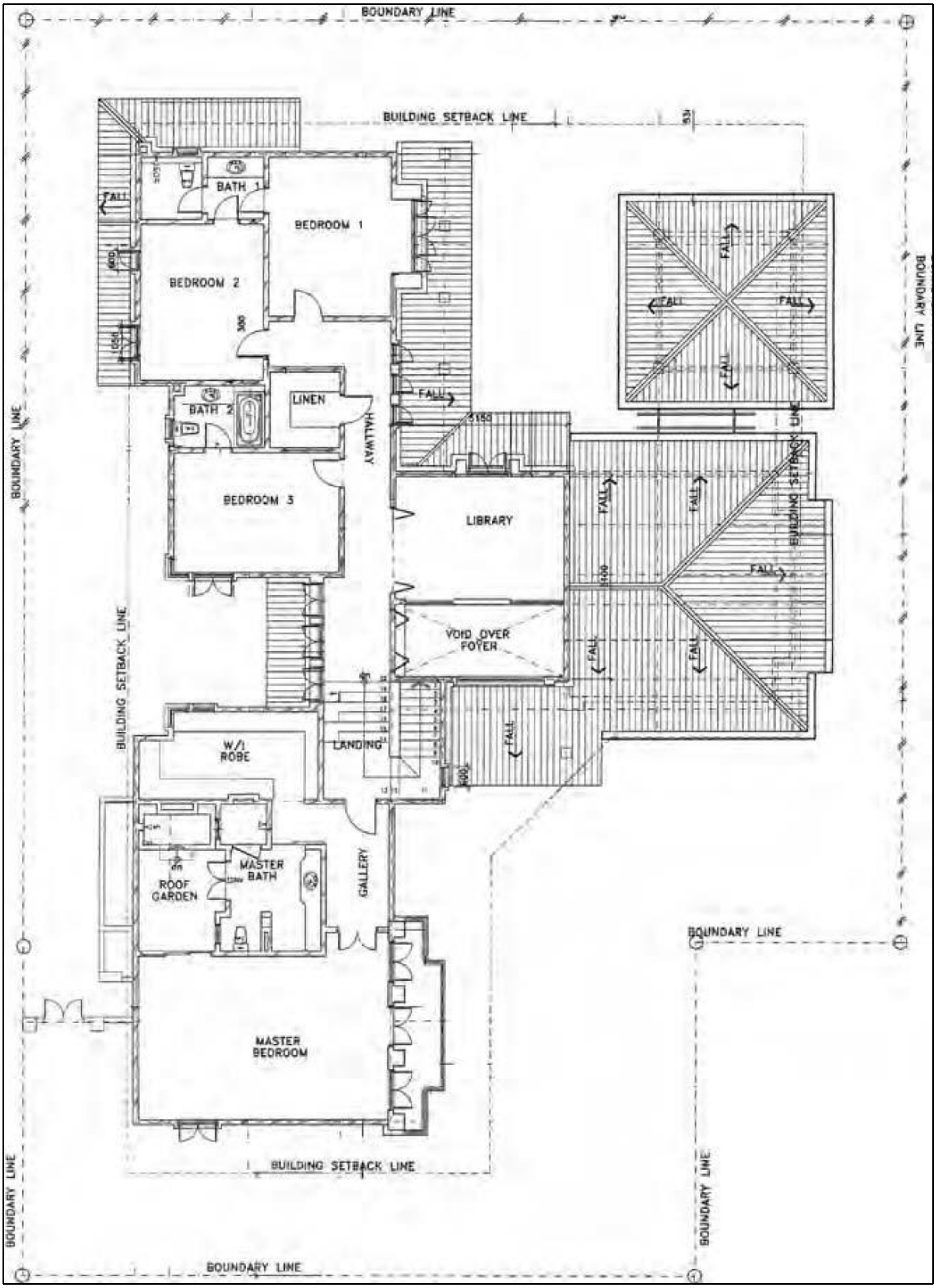


Figure 2.21 The first floor plan of the contemporary tropical house at Kayangan Heights, Shah Alam, Malaysia, showing numerous functional spaces and multi-level design; source: Ahmad (2008, p.286).

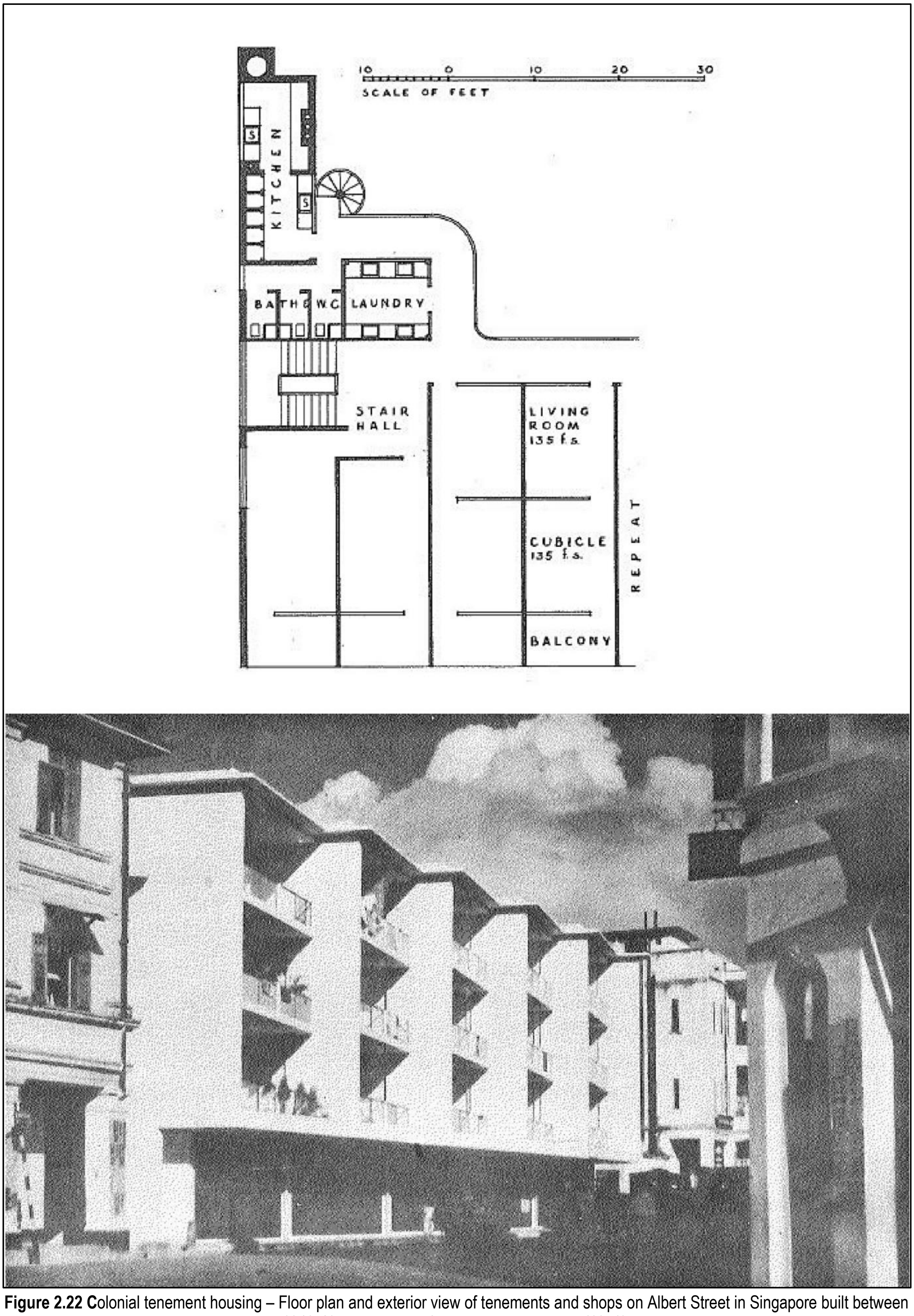


Figure 2.22 Colonial tenement housing – Floor plan and exterior view of tenements and shops on Albert Street in Singapore built between 1948-49; source: The Colonial Building Notes (1950).

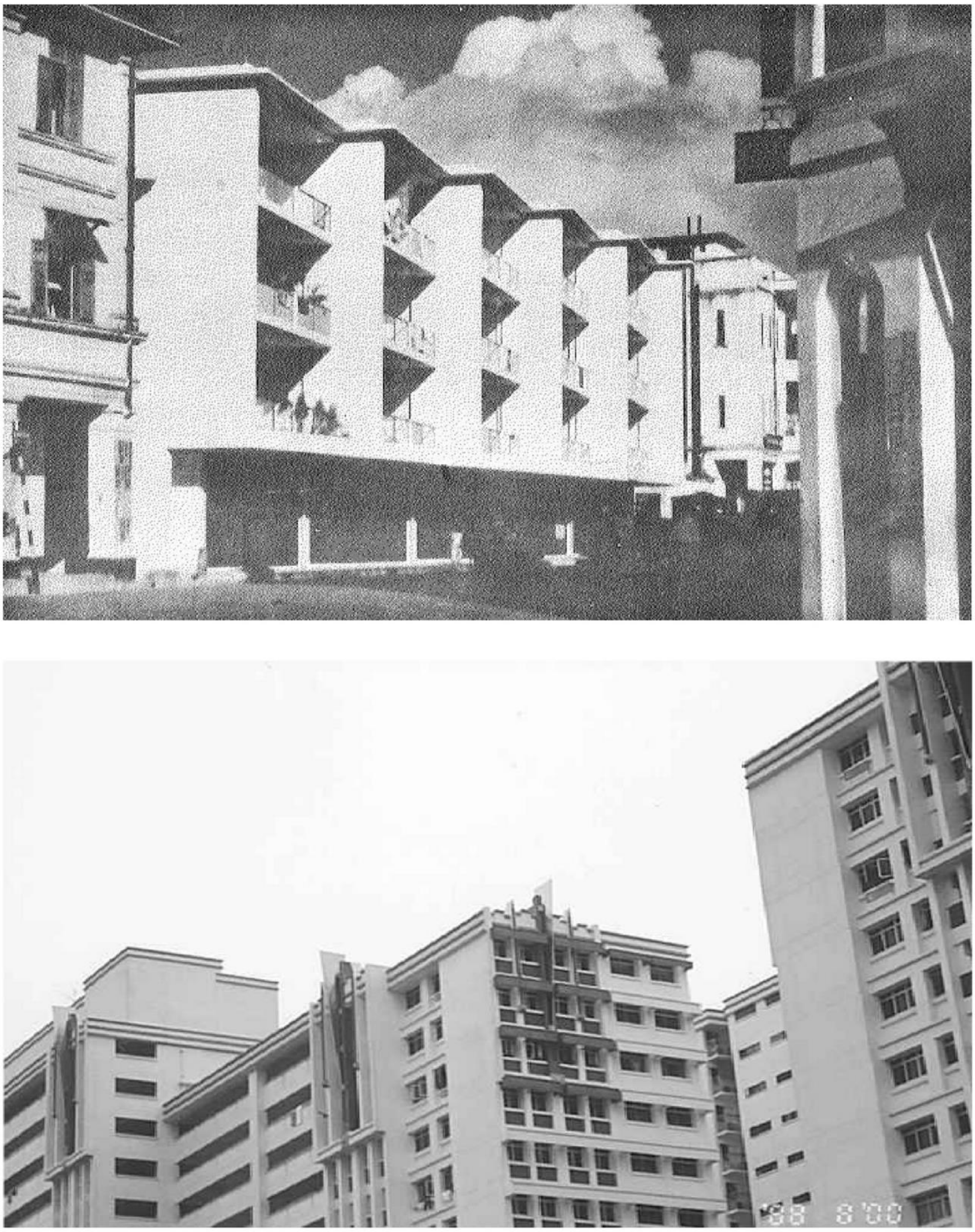


Figure 2.23 The similarities between 1990s tenement housing (bottom building) and 1940s tenement housing (top building) in Singapore, showing as similar geometry and balcony features ; source: top building (Ibid) and bottom building (Goh, 2001, p.1597).

themselves as the people in the higher economic classes do. They create sub-standard copies of contemporary house types, which are also classed as informal settlements; this prevails in Asia and Latin America, even more than in Africa (Danby 1971). Others live in suburbs and rural areas in the hinterlands where housing shows a mix of traditional, colonial and contemporary styles (Karol & Chin Lai, 2014). Even in these parts, the influence and affluence of urbanism is well-known and there is an ever-present desire to live by norms of modern society (Alcock, 1969; Danby, 1971; O'Brien, 2006). Hence, rural-urban and rural-suburban migration is often craved. Still, the sense of community is preserved in these parts. Some variants have a mix of dispersed traditional space syntax, with lavatories and kitchens being separate from communal and sleeping spaces yet built in colonial construction. Others employ Colonial space morphology with contemporary construction.

As hinted earlier, contemporary construction in the hot-humid regions features elements of the International style. The International Style continues to reflect in housing in many tropical regions. The predominant materials which produce the quadrangular box-like houses are concrete, metal (mainly steel and aluminium) and glass (Karol & Chin Lai, 2014). Concrete block walls and reinforced concrete columns, with glass-paned, aluminium-framed Jalousie or sliding windows and timber-trussed, aluminium-covered roofs, display the character of a typical middle-income contemporary house structure in the hot-humid regions (Butera, Adhikari & Aste, 2014). The sub-standard variants would feature corrugated zinc or iron sheets instead of aluminium; timber louvered windows instead of glass and sandcrete blocks in place of concrete (Danby, 1971). Many mass housing projects employ the typical construction character. Utilities go along with contemporary construction; electrical and water supply systems are installed, despite the unreliability of public services in many developing countries with hot-humid climates (Atkinson, 1960). In many hot-humid regions, air conditioning units are common as well as generating sets as a stand-by source of electrical power, in houses belonging to middle- and high-income earners (RUWES, 2015). These are features that have elevated the cost of contemporary housing in terms of materials and skill, in these places (O'Brien, 2006). Although, most of these materials are now being produced indigenously, the societal inequality magnifies the inability of low-income earners to afford the best kind of contemporary housing (Danby, 1971; Atkinson, 1950). There is an assertion that the compact space morphology of contemporary housing indicates its cost-effectiveness; however, expenses on materials and construction outweighs this positive (Moriarty, 1980; Kamal, Wahab & Ahmad, 2004). Still, the fact that contemporary construction seems more durable than traditional construction, continues to encourage the advance of the former (Ibid; Atkinson, 1950). Moriarty (1980, p.288) illustrates this by pointing out that metal sheet roofing is "*strong and light… involves less skill than constructing a good thatch roof*."

The reviews on contemporary housing in hot-humid regions raise interesting points about the climate-responsiveness and climate-suitability of the housing. Contemporary houses such as apartment blocks feature low ceilings to save cost, resulting in less air circulation and more thermal discomfort; thus, mechanical controls such as air conditioning units have become a fundamental feature (see Figure 2.24). The presence of more windows due to more spaces in the contemporary house, creates potential for cross ventilation, by admitting gentle breezes of the warm-humid equatorial climate (Prianto et al, 2000).

However, as these windows are smaller than colonial versions and made of glass which facilitates large amounts of solar heat gains. As such, authors such as Butera, Adhikari & Aste (2014) recommend louvered windows and door as a fenestration solution in hot-humid climates, as they encourage cooling and security. However, Kamal, Wahab & Ahmad (2004) compare the Jalousie/louvre windows to the

Figure 2.24 A contemporary tenement building with air conditioning units installed in flats; source: Goh (2001, p.1598).

traditional casement windows and report that the former disrupt air flow creating less comfortable interiors. In addition, the contemporary space morphology redolent of Colonial housing, does not facilitate air flow as much as the openness of the traditional space syntax does (Prianto et al, 2000). Consequently, the heavy dependence of artificial cooling is a standard feature of the contemporary house. This has been criticised as well as air conditioning units and generating sets release destructive, waste gases into the atmosphere contributing to climate change and worsening the unbearable intensity of the hot-humid climates (Thiele, 2013). Prianto et al (2000) further summarise that the increased freedom of contemporary self-build has brought more concerns as home-owners driven by the lavishness of western urban housing do not consider the suitability of such housing to their contextual climates. However, contemporary houses of the elite have shown positive form-climate responses. Many are raised above the ground, have many, large fenestrations and high head rooms promoting better air flow than the traditional predecessors (Uduku, 2006).

Accordingly, it may seem that contemporary construction has been more ridiculed than approved, in terms of suitability to the warm-humid equatorial climate (Karol & Chin Lai, 2014; Kamal, Wahab & Ahmad, 2004). The metallic and glass components have low thermal resistance properties, allowing easy transfer of heat into interiors (Salmon, 1999). As the problem in hot-humid climates includes the intense heat, researchers have stated that the aim of building in the tropics is to keep interiors as cool as possible (Koenigsberger et al, 1974; Prianto & Depecker, 2002). Therefore, metal roofs and glass-paned windows have been declared unfit for the hot-humid climates (Moriarty, 1980). Kamal, Wahab & Ahmad (2004) refer to the fact that metal roofing sheets can make for noisy interiors when frequent and heavy rains fall. On the other hand, contemporary pitched roofs have been praised for possessing ventilated spaces above the walled interiors, encouraging the stack effect which promotes cooling (Prianto et al, 2000). It may seem that this stifles the negatives of the metallic roof elements (Moriarty, 1980). Concrete has received much negative light in terms of suitability to the climate. Many studies have indicated that perceived comfort is better in the dwellings with traditional earthen or timber walls than in those with the concrete or masonry walls (O'Brien, 2006). Still there is a case for concrete and masonry walls due to their high thermal mass and low thermal resistance properties (Butera, Adhikari & Aste, 2014; Salmon, 1999; SEAV, 2002). Quantitative studies have revealed that concrete walls create more even and cooler temperatures than traditional earth or timber walls (Latha, Darshana & Venugopal, 2015; Cheng, Ng & Givoni, 2005). Earthen and stone walls have been reported to possess good thermal performance due to high thermal mass and low thermal resistance properties (Butera, Adhikari & Aste, 2014). However, in other areas governed by socio-economic criteria, there is an interesting tussle between traditional and contemporary wall materials in current sustainable housing in the hot-humid regions. This will be explored later.

Examining the leaning of many authors on this subject can lead one to conclude that contemporary housing in the hot-humid regions is a necessary evil on the surface. However, with critical examination of its different aspects, tropical contemporary housing may have more potential to provide adequate housing in contextual milieu, than it is given credit for (Latha, Darshana & Venugopal, 2015). The obvious problems of this housing include unaffordability and unsuitability to climate and culture. This has inspired architects and builders involved, have begun to explore innovative ways of combating these issues (Tessema, Taipale & Bethge, 2009). It is obvious that much research tends towards the acclaim of traditional building because of its socio-economic and environmental values (O'Brien, 2006). This school of thought insinuates the development of rural settlements using smart, nature-based technologies to provide basic amenities/utilities like water in-house for traditional domestic dwellings. Eco-villages such as the Thlolego Ecovillage, Rustenburg, South Africa, show this idea (Tessema, Taipale & Bethge, 2009).

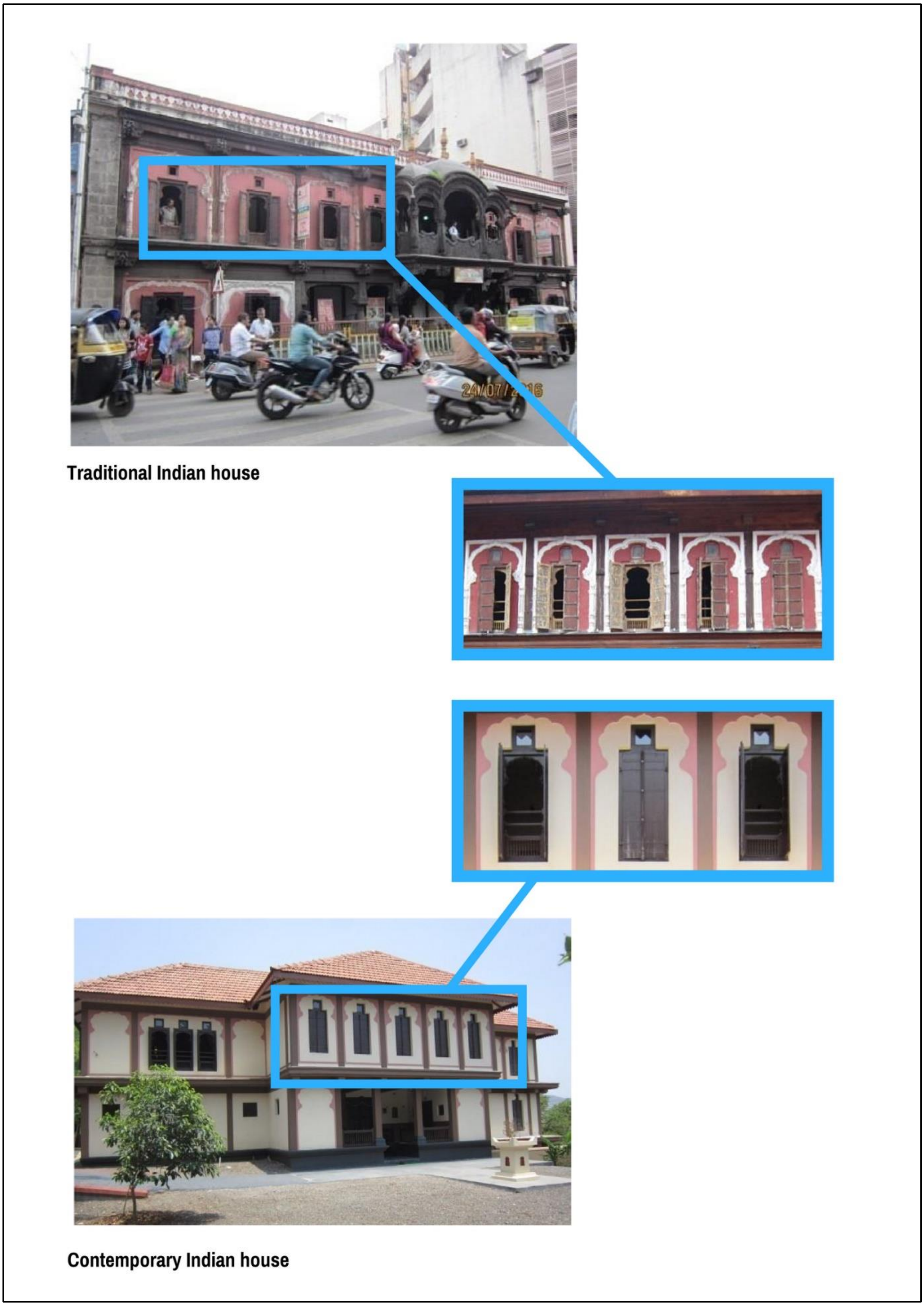


Figure 2.25 A contemporary house which features influences from a similar traditional house in India; source: Dhepe & Valsson (2015, pp.15, 19, 20, 15 (from top to bottom)).

Others argue that there can be no complete return to the past as societal changes due to technological advancements, have made life easier (Karol & Chin Lai, 2014). Therefore, the most popular research trends involve the augmentation of tropical contemporary housing with traditional techniques and improvements brought about by engineering research (Tessema, Taipale & Bethge, 2014; Egenti, Khatib & Oloke, 2014). Many studies prescribe standards for contemporary tropical construction, which are fast creating different variants of cost-effective, eco-friendly and social housing in the tropics. Even more, the results of this movement have created a contemporary architectural style known as 'tropical architecture': "…*a type of green building applicable specifically for tropical climates, using design to optimally reduce buildings' energy consumption, particularly the cooling load*." (UNESCAP, 2011). Tessema, Taipale & Bethge (2009) give an informative report on the nature of the alterations made to contemporary housing in the tropics. Among their case studies are South African housing projects where walls are built of recyclable waste products such as straw and urban mass housing units are retrofitted to reduce dependence on electrical energy.

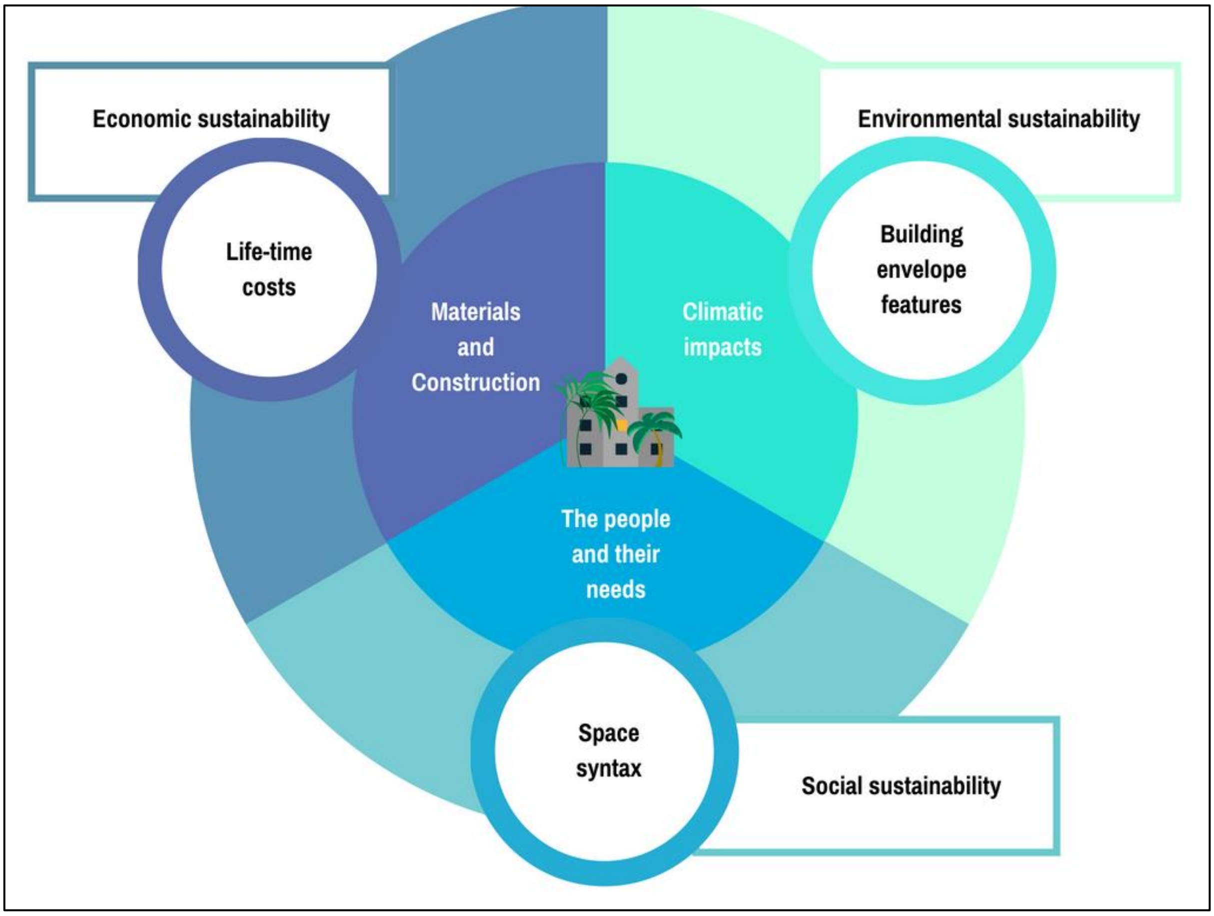


Figure 2.26 The basic housing responses in tropical climates, corresponding with the principles of sustainability; source: author's study.

Table 2.3 Summary of tropical housing based on chronological and climatic responses.

Criterion	Traditional Housing	Colonial Modern Housing	Contemporary Housing
Symbol	Origins	Transition	Advancement
Location	Villages/Oldest living areas	Urban centre/mature areas	Urban periphery/new areas
Style	Rustic (earth & timber character), indigenous ornamentation (carved columns, eaves etc) Low ceilings	Western (Cement and Iron character), ornamental, experimental (indigenous+western) Higher ceilings	Western (International Style predominant) Mixed (combinations of traditional, colonial & modern styles)
Construction/Materials	Roof: timber, thatch, earth, bamboo Wall: timber, earth, bamboo Floor: earth Low durability & structural strength	Roof: timber, metal (zinc, corrugated iron, aluminium) sheets, asbestos Wall: cement/concrete bricks Floor: cement slab Intermediate durability & structural strength	Roof: timber, metal (zinc, corrugated iron, aluminium) sheets, asbestos, earthen tiles Wall: cement/concrete, sandcrete blocks Floor: cement/concrete slab High durability & structural strength.
Form	Quadrangular, Circular, Triangular. Usually one-storey. Dispersed spaces in a major area.	Quadrangular. One-storey, Multi-storey.	Quadrangular, Cuboidal, Cellular. One-storey, Multi-storey.
Ventilation features	Very open facades. Casement doors & windows. Piled roofs with rifts in-between. Courtyards, impluvia.	Very open facades. More doors and windows with greater dimensions. Attics, corridors and verandas. Overhanging roofs. Variable (sometimes high, sometimes low) ceilings with ventilators.	Open facades but with barriers. Doors and windows of moderate sizes. Overhanging roofs.
Utilities	Minimal or completely absent. Crude technology such as rainwater harvesting and storage for water supply, biomass burning for heat and light.	Limited. Introduction of fans and ventilators for cooling. Simple piping systems for water supply and circulation. Improved and safer heat generation using fossil fuels. Introduction of electricity for lighting and household appliances.	Abundant. Electric cooling devices including air conditioners, lighting and household appliances. Installed Water supply systems.
General Climatic Responses	Largely environment-friendly, natural ventilation systems.	Environment-friendly to an extent. Natural ventilation systems were augmented mechanically.	Minimal or no environmental-friendliness. Use of extensive technology to cool intense heat.

Source: author's study; template by Prianto et al, 2000.

In addition, combinations of traditional and contemporary building techniques characterise new contemporary housing (see Figure 2.25). Materials are being engineered with improved properties that reduce the effects of the harsh hot-humid climate (Latha, Darshana & Venugopal, 2015; Tessema, Taipale & Bethge, 2009; Danby, 1971; Egenti, Khatib & Oloke, 2014). Adjustments are being made to the facades of contemporary housing in the subject regions. Experimental research on the thermal performance of traditional and contemporary housing in hot-humid climates is very current (Karol & Chin Lai, 2014; Latha, Darshana & Venugopal, 2015). However, all these studies on tropical contemporary housing, seem to address the main problem of the tropics mentioned earlier: thermal comfort derived by cooling and dehumidification. As such, ways of assessments of thermal comfort have been developed.

2.6 Thermal comfort in hot-humid climates

Earlier in the study, thermal comfort was defined: "*condition of mind that expresses satisfaction with the thermal environment*…" (ASHRAE, 2017, p.9.1); the condition where the occupant of a space does not feel too hot or too cold that is when he/she is thermally neutral (SWEGON, 2014). Furthermore, it has been established that thermal comfort can either be objectively perceived through quantifiable environmental elements, or subjectively assessed through individual judgements. As previously mentioned, the most significant environmental factor: air temperature and the subjective thermal responses determine thermal comfort. Therefore, Szokolay (1980; 2014) states that within a space, a comfort zone is created where environmental temperatures allow the right amount of heat dissipation, causing a range of acceptable comfort conditions for most people. Additionally, Koenigsberger, et al (1974) define the comfort zone as the range of conditions where a minimum of 80% of people are comfortable. The temperature boundaries of the comfort zone are relative to the neutral temperature (Tn). Therefore the comfort zone for 90% of people may be defined as (Tn – 2.5)°C to (Tn + 2.5)°C. These two assessment methods of thermal comfort have become the foundation for the distinction between two approaches or models in thermal comfort research – the adaptive approach and the static approach. These two approaches aim to identify acceptable thermal comfort conditions.

The static or traditional approach focuses on the responses of the human body to its immediate thermal environment (de Dear & Brager, 1998). It focuses primarily on what the occupants sense of their immediate thermal environment, where the only changes are clothing (Hensen & Centnerova, 2001). Hence, the static approach has been deemed applicable across all building types in all climates; users of a space indicate their perceived levels of comfort based on indoor climatic parameters such as air temperature, humidity and velocity. ASHRAE (2009) looks deeper at the subjective or sensory thermal comfort assessment and explains that the determinants of users' perceptions can be tied to clothing and metabolism. As is the case with subjective assessments, the challenge here is quantifying the perceptions of individuals. Consequently, rating systems which help users to express their perceptions of comfort have been developed (Ibid). These systems derive a relationship between environmental and physiological factors to produce a balanced assessment of thermal comfort.

Very notable among these rating systems is Fanger's system, which is based on an equation he developed. Ellsworth-Krebs, Reid & Hunter (2015, p.101) say of Fanger's work: "*Fanger clearly understood comfort as the result of complex interaction between multiple criteria, his work helped to lead to the perception and acceptance of comfort as a definable condition and establishment of universal standards for the indoor environments*…". More specifically, Fanger's system is called the Predicted Mean Vote (PMV) which is a thermal scale that runs from cold (-3) to hot (+3) (Autodesk, 2011) (see Figure 2.28). He cultivated his system by gathering responses- based on the scale- from thousands of people

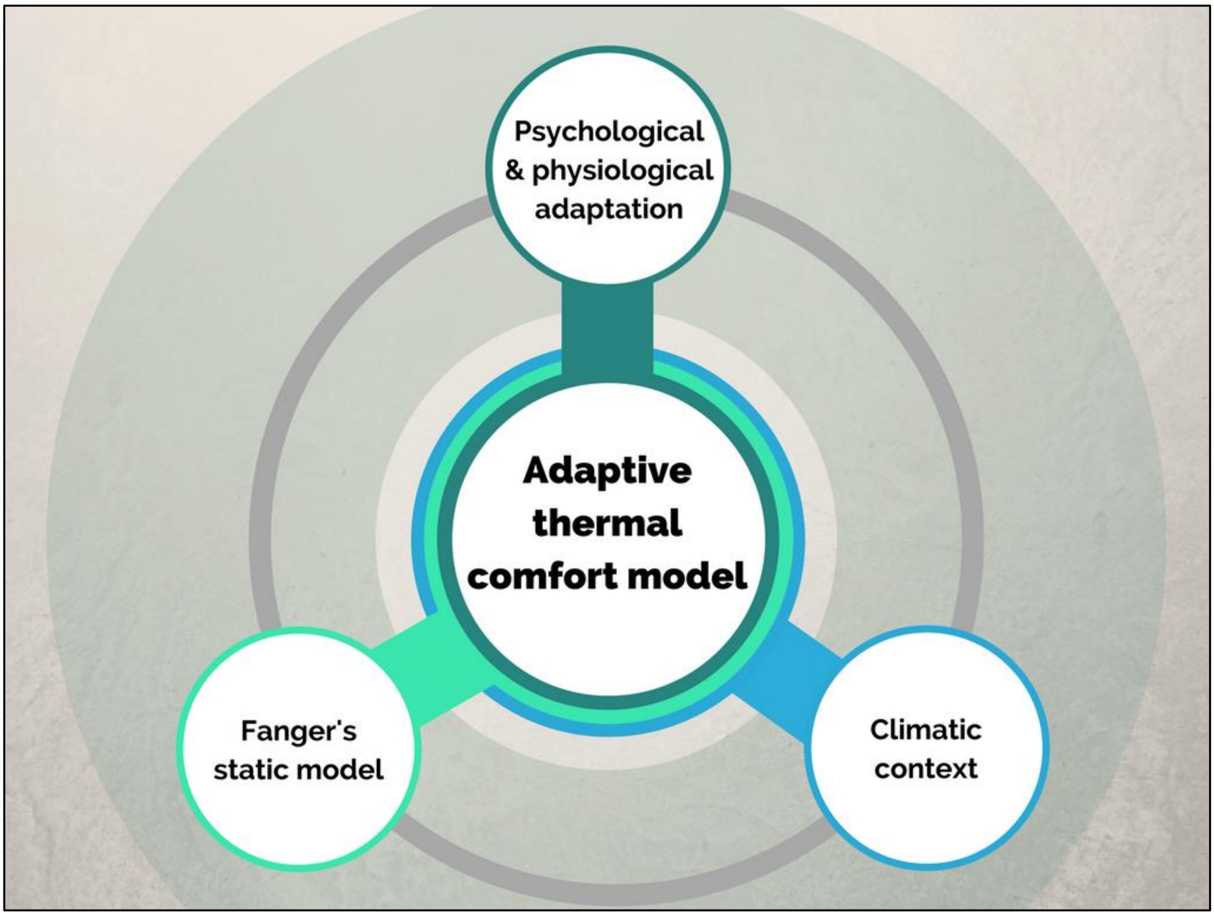


Figure 2.27 The adaptive thermal model, its relationship with the static model and other elements; source: author's study.

who he subjected to various climatic conditions within a climate chamber (Ibid). Subsequently, Fanger evolved a mathematical model of the connection between all environmental and physiological components extracted from all the data. Autodesk (2011) shows Fanger's PMV scale, explaining that the results of the mathematical model "*relates the size thermal comfort factors to each other through heat balance principles producing the following sensation scale*." Researchers have referred to the adaptive model or assessment as the 'Comfort Vote' because of Fanger's work (Akande & Adebamowo, 2010). Hence, the different points on the scale tally with certain physical values within the space; for instance, researchers note the temperature and humidity levels when most occupants vote 0 (neutral) or +1 (slightly warm). Derivatives of Fanger's PMV scale exist: the Predicted Percentage of Dissatisfied (PPD) envisions the proportion of users that will be dissatisfied with the thermal environment (Autodesk, 2011).

Accordingly, the most internationally acclaimed bodies involved in building assessment - the American Society for Heating, Refrigeration and Air-Condition Engineers (ASHRAE) and the International Organisation for Standardisation (ISO)- have employed Fanger's model for their thermal comfort models. Hence static approaches to thermal comfort in residential spaces are governed by ASHRAE Standard 55-1992 and ISO 7730. However, de Dear & Brager (1998) point out the major weakness of the static approach. In the words of de Dear & Brager (1998, p.1) "…*many researchers are beginning to challenge the assumption of universality, arguing that it ignores important cultural, climatic, social, and contextual dimensions of comfort, leading to an exaggeration of the need for air conditioning*…" Hence, the static model omits consideration for the influence of outdoor climates on indoor environments (see Table 2.4). Nicol (2004) supports this claim by stating that researchers have found that PMV is better suited to air-conditioned buildings because the comfort perceptions of occupants have already been programmed towards air-conditioned spaces. Furthermore, the adaptive approach takes into cognisance not only behavioural adjustments-altering fenestrations and clothing- of occupants to their thermal surroundings, but also the occupants' intangible psychological and physical acclimatisation that occurs (Hensen & Centnerova, 2001) (see Figure 2.27). Psychological acclimatisation entails altered perceptions and reactions to sensory information based on past experiences while physiological acclimatisation involves a gradual reworking of response type to an environment due to prolonged exposure to that environment (de Dear & Brager, 1998). Correspondingly, new thermal comfort standards are being cultivated for naturally ventilated/free-running buildings and thermal environments where the indoor environments are linked with the climatic context of the building as well as the past and present experiences of occupants (de Dear & Brager, 1998; Hensen & Centnerova, 2001). These findings have been well-received by ASHRAE (Mallick, 1996; de Dear & Brager, 1998).

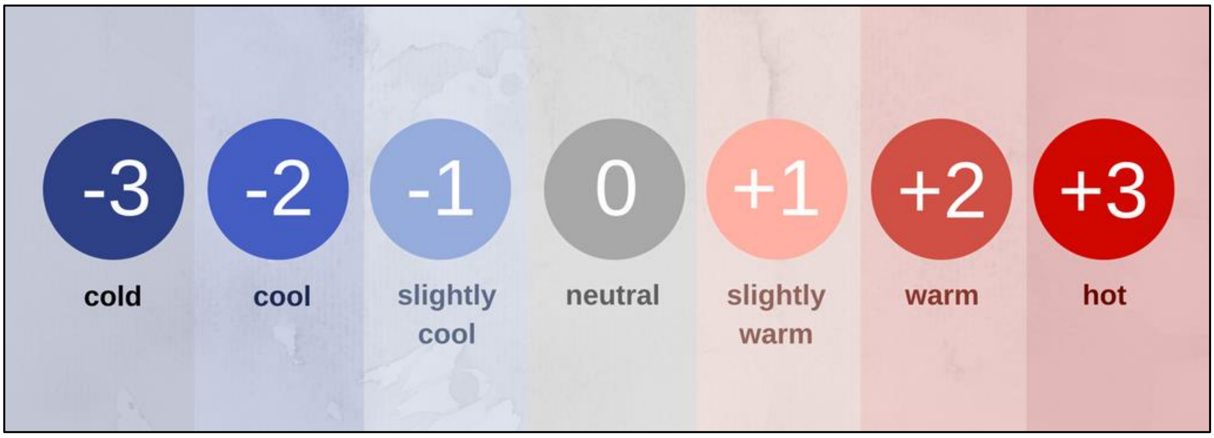


Figure 2.28 Fanger's PMV scale; source: author's study.

The adaptive approach to assessing thermal comfort involves definitions of comfort levels in indoor environments, per the experiential perceptions of the occupants or users of the space and the climatic context of the building (Akande & Adebamowo, 2010). Nicol & Humphreys (2002, p.46) indicate that the adaptive approach is based on the adaptive principle: "*If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort*." Furthermore, in the actual words of Akande & Adebamowo (2010, p.2), "…*The adaptive approach to thermal comfort is based on the findings of surveys of thermal comfort conducted in the field study. Field surveys concentrate on gathering data about the thermal environment and the simultaneous thermal response of subjects in real situations, interventions by the researcher being kept to a minimum*…". Hence, a main principle of the adaptive approach is the consideration of the active role that occupants play in creating their acceptable thermal environments (de Dear & Brager, 1998). Humphreys' work on the adaptive thermal model has received much attention; his study utilised data from over thirty surveys in various regions across the globe (Schumacher, Wortel & Wieringa, 2001). Schumacher, Wortel & Wieringa (2001, p.179) further report Humphrey's conclusions that "…*the comfort temperature also depends on the country of origin in a way, which appears to be unrelated to the climate*." On the other hand, Fanger (1993) maintains that it is the static, not the adaptive models, that support the basic rule of ergonomics: the machine should adapt to man (in Schumacher, Wortel & Wieringa, 2001). However, the machine here is the climate of a location, and if that machine must adapt to man, fundamental terrestrial balances will be upset and life endangered in the long run (UNEP, 2011; Thiele, 2013). Nevertheless, the adaptive thermal approach is becoming increasingly popular as it fits with the current sustainability principles.

Thermal comfort models are essential in observing patterns and determinants of different climatic conditions within a space. The goal of observing the thermal environment is to establish an acceptable thermal environment. ASHRAE (2010, p.3) defines an acceptable thermal environment as "*an*

Table 2.4 Limitations to the range of conditions over which Fanger's PMV applies.

Variable	Symbol	Units	Lower limit	Upper limit
Metabolic rate	M	W/m^2 (met)	46 (0.8)	232 (4)
Clothing insulation	I_{cl}	°C/W (clo)	0 (0)	0.310 (2)
Air temperature	t_a	°C	10	30
Radiant temperature	t_r	°C	10	40
Relative air velocity	v_{ar}	m/s	0	1.0
Water vapour pressure	p_a	Pa	0	2700
Predicted mean vote	PMV		-2	+2

Source: author's study; based on Nicol's (2004) table.

environment that a substantial majority of the occupants would find thermally acceptable." Studies have associated thermal neutrality with an acceptable thermal environment where most occupants indicate comfort within a set of physical values (Han, Zhang, Zhang, Zhang, Liu, Tian, Zheng, Hao, Lin, Liu & Moschandreas, 2007; Mallick, 1996; Adunola, 2014; Cheng, Ng & Givoni, 2005). Thermal neutrality is "*the indoor thermal index value corresponding with a mean vote of neutral on the thermal sensation scale*" (ASHRAE, 2010, p.3). SWEGON's definition of thermal comfort is based on the description of a thermally neutral environment where the occupant is neither too hot nor too cold (SWEGON, 2014). Thus, the environmental values linked to thermal neutrality have become accepted as the values that indicate the acceptable thermal environment for respective occupants. These values constitute a specific figure or a range of figures. For example, ASHRAE Standard 55-1992 states optimum temperature at 22 °C and acceptable temperature range at 20 to 23 °C in winter (Charles, 2003). Another instance: Han et al (2007, p.4047) in their study on thermal comfort in hot-humid central southern China stated "*The neutrality value is estimated by solving Eq. (2) for a mean TSENS value equal to zero denoting a comfortable thermal environment; the neutral operative temperature is 28.6°C*." Consequently, the search for thermal neutrality and an acceptable thermal environment is very current, especially in extreme climates such as the hot-humid tropics.

Correspondingly, the ASHRAE 55 and ISO 7730 standards have become internationally recognised thermal comfort standards with sections tailored to the needs of different climatic zones, including hot-humid climates (Ellsworth-Krebs, Reid & Hunter, 2015; Han et al,2007). Accordingly, many studies on thermal comfort in the tropics have utilised these standards (Nicol, 2004). However, as the standards are fundamentally referred to as static and based on experiments in temperate regions, authors have attempted to test the suitability of ISO 7730 and ASHRAE 55 to the tropics. de Dear, Leow & Ameen (1991), as stated by Nicol (2004), confirmed that the standard was suitable in the tropical environment.

However, Nicol (2004) and Adunola (2014) indicate that ISO 7730 may be limited in its appropriateness to the hot-humid climates because temperatures in those climates exceed those represented by the PMV scale. Lopez, Lucchese & Andreasi (2015) point out that Fanger's PMV's appropriateness for hot-humid climates is questionable as it was cultivated using adapted climate chambers. Still, Mallick (1996) demonstrates that ASHRAE 55 might be more suitable to the hot-humid tropics as it accepts the acclimatisation better than ISO 7730 by stipulating a higher temperature for summer. There are more studies, maintaining that the acceptable temperature levels in hot-humid climates are higher than ISO 7730 thermal comfort temperatures, than studies that present similar facts on ASHRAE 55 (Lopez, Lucchese & Andreasi, 2015; Mallick, 1996; Han et al, 2007; Larr & Grimme, 2002). Han et al (2007) use ASHRAE 55-1992 as the reference point for their thermal comfort standard, despite their opinion that ASHRAE 55 and ISO 7730 are not completely appropriate for the hot-humid tropics.

Furthermore, authors have raised the issue of acclimatisation of people living in hot-humid climates to the higher temperatures and humidity levels (Mallick, 1996; Szokolay, 1980; 2014). Hence the perceived levels of comfort stipulated by the popular comfort indices, which were developed in mechanical climate chambers, may be too cool for people in the hot-humid tropics. Moreover, Mallick's 1996 study on thermal comfort in residential homes in hot-humid Bangladesh, specifically reveals that people were most comfortable in air temperatures of 24 to 32 °C and humidity levels of 90%. These comfort ranges clearly exceed the 30°C upper limit of the Fanger sensational scale (Nicol, 2004). On the other hand, Larr & Grimme (2002, p.160) state that "*ASHRAE accepts some acclimatisation by specifying a higher temperature range*…" but "*some studies indicate an even higher average comfort temperature for the hot-humid tropics*…" Han et al (2007) reinforce Larr & Grimme's (2002) later objection to ASHRAE's suitability, by stating that the standard does not properly account for human adaptation to extreme temperature and humidity levels by adjusting fenestrations and clothing. Still, ASHRAE 55 remains a relevant tool in assessing thermal comfort in the hot-humid climates, regardless of all the inadequacies of the system which authors have identified. As the standard has been modified to accommodate the adaptive principle, the latest versions include ASHRAE 55-2010 and ASHRAE 55-2013 (ASHRAE, 2010; ASHRAE, 2013). Accordingly, ASHRAE 55 seems to be the most popular standard among studies on thermal comfort in the tropics (Han et al, 2007; Adunola, 2014; Akande & Adebamowo, 2010).

Research on thermal comfort in the tropics is carried out using field surveys where physical parameters such as air temperature, relative humidity and air velocity are measured (Akande & Adebamowo, 2010). In addition, these field surveys involve collating the comfort votes among space users, while identify the temperatures that tally with the majority comfort votes (Han et al, 2007; Adunola, 2014). Alternatively, some studies utilise computer simulation to develop optimal thermal comfort in virtual models of real-life spaces (Hensen & Centnerova, 2001; Mirrahimi, Mohammed, Haw, Ibrahim, Yusoff & Afaki, 2016; Mallick, 1996). Apart from utilising comfort votes, authors have found that the number of discomfort hours observed in a space is a good indicator of indoor thermal comfort. A discomfort hour seems to be synonymous with an hour of exceedance (Nowak, Nowak-Dzieszko, & Rojewska-Warchal, 2013; Clark, 2013). Clark (2013, p.7) defines the hours of exceedance as "…*the number of hours the predicted operative temperature exceeds the maximum acceptable operative temperature (Θ_{max}) by 1°C or more*…" Studies have shown that when the number of discomfort hours exceeds a standard number for a certain period, the concerned space is deemed thermally uncomfortable (Ibid). However, the reduction in the number of discomfort hours, and compliance of the number with the stipulated range, are taken as indications of positive thermal comfort (Nowak, Nowak-Dzieszko, & Rojewska-Warchal, 2013).

A common research trend among studies on thermal comfort in the tropics is the focus on comparing the thermal performance of traditional and contemporary domestic building envelopes in the hot-humid regions (Mirrahimi et al, 2016; Mallick, 1996; Cheng, Ng & Givoni, 2005; O'Brien, 2006; Latha, Darshana & Venugopal, 2015). These studies reveal the innate optimisation of the traditional building envelope to establish a positive internal environment in relation to outdoor climates. On the other hand, the optimisation of the contemporary building envelopes seems acquired and intentional. Hence optimisation of modern building envelopes is often done in virtual environments, by altering the construction detail of different parts of the building envelope (Mirrahimi, et al, 2016). The impact of these alterations in creating acceptable thermal environments is recorded and suggested as a guide for building envelope construction in the tropics.

There is a principal focus on thermal comfort with regards to temperature (Ellsworth-Krebs, Reid & Hunter, 2015); studies on thermal comfort have verified this as humidity levels have proven too extreme to passively control or occupants have adapted to the humidity (Mallick, 1996). Adunola (2014) states that the thermal environment within a building is a product of the synergy between architecture and climate. Olaniyan, Ayinla & Odetoye (2013, p.1373) reiterate that "*the thermal performance of a building is the degree at which the building modifies the prevailing outdoor climate to create a unique indoor environment*." Hence, many studies on thermal comfort in the tropics examine the role of the building envelope (fabric) in creating optimal temperatures in indoor climates. Many findings infer that contemporary building envelopes are responsible for poorest thermal performance (Olaniyan, Ayinla & Odetoye, 2013; O'Brien, 2006). Therefore, the augmentation of contemporary building envelopes with construction principles of traditional building envelopes has become popular. This reflects a new housing concept - the augmentation of contemporary housing with traditional housing elements. Consequently, more inquiries into innovative materials and construction which can be cheaper and eco-friendly while providing thermal comfort, have been inspired. Studies have revealed the advancement of traditional mud wall construction and currently, rammed earth and earthbag walls form modern building envelopes that are cost-effective, green and perform optimally in terms of structure and thermal comfort (Tessema, Taipale & Bethge, 2009). Moreover, much emphasis has been placed on the fact that acceptable thermal environments reduce dependence on HVAC systems and consequently, costs and energy-use (Mirrahimi et al, 2016). With reduced dependence on HVAC systems, there is hope that emissions from buildings that foster climate change, will decline (Ibid; UNEP, 2011). Therefore, these studies are beginning to stipulate that designers re-embrace principles of climatic design, which focus on creating building envelopes that perform optimally, without any input from mechanical thermal controls.

2.7 Principles and Approaches to tropical building envelope design for optimum thermal comfort

Section 2.3.4 considered the way the building envelope facilitates thermal comfort of the indoor environment. The previous section investigated thermal comfort standards applicable in the tropics. Thus, this section ties those two discussion threads together by outlining the principles and approaches to achieving thermal comfort through the building envelope in the tropics. The following design parameters governing the building envelope's thermal performance have been gleaned from Koenigsberger et al's (1974) and Szokolay's (1980; 2014) texts on tropical climatic design.

1. **Fabric**

The roof, wall and floors can perform optimally if the following are considered:

- Shading;
- Surface qualities (absorbance, reflectance, conductance);
- Thermal insulation (reflective and resistive);
- Thermal inertia (capacitive insulation);
- Relative position of capacitive and resistive layers.

2. **Fenestration**

Windows can facilitate the highest heat gains from solar radiation (Koenigsberger et al, 1974). Therefore, the designer should control the following elements to reduce the amount of solar heat gain through windows:

- Size, orientation, distribution and placement
- Glazing type: heat-absorbing, heat-reflecting and low-e glasses can prove useful in curbing solar heat gains; however, they should be used with caution as as to not compromise adequate daylight

(Szokolay, 2014). Koenigsberger et al (1974) explain that heat-absorbing glasses operate by selective transmittance where the radiation absorbed is selected. Similarly, heat-reflective glasses work by selective transmittance as well but by selecting the radiation that is reflected. these glasses absorb very little heat because the glass is coated, through vacuum evaporation, with a thin film of metal (gold or nickel is commonly used).

- Internal elements (blinds, curtains): Koenigsberger et al (1974) state that although curtains and blinds are not very effective at solar control, they can stop the transmission of solar radiation. However, they soak up radiation and can cause the mean radiant temperature to exceed the air temperature indoors.
- Shading devices.

3. **Ventilation**

- Mass transfer (convective) cooling or ventilation rate;
- Physiological cooling or air velocity.

These parameters are influenced by orientation, fenestration, seals and closing mechanisms.

4. **Solar Control and Shading Design**

The sun's position in the sky hemisphere per time is determined by two angles which are:

- The azimuth (α);
- The altitude (γ).

These angles define the sun's position with respect to geographical coordinates (see Figure 2.29). Therefore,0° azimuth represents north and 0° altitude is the horizontal. However, when the sun's position is considered in relation to the building face, two additional angles are used:

- The horizontal shadow angle or azimuth difference: $\delta = \alpha - \omega$, where ω is the building face orientation;
- The vertical shadow (ϵ): the projection of the solar altitude angle on a plane at a right angle to the building face.

When the sun is directly facing the building face,

- the building face orientation is equal to the azimuth ($\omega = \alpha$),
- the solar angle is the same as the vertical shadow angle ($\gamma = \epsilon$)

When the sun is facing another side of the building orientation, the vertical shadow angle (ϵ) is greater than the solar altitude (γ).

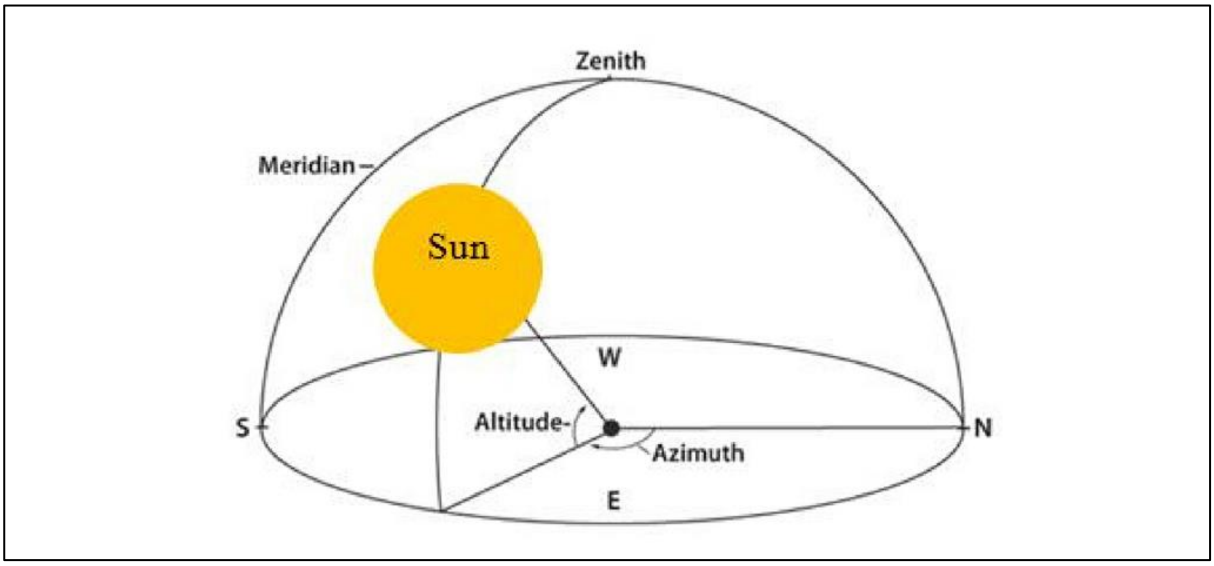


Figure 2.29 Azimuth and altitude angles used in solar design; source: Sidek et al (2014, p.246).

An understanding of solar angles is needed to execute adequate shading design. Shading design is based on the meaning of the overheated period. The overheated period is the part of the day where no solar input is needed and all windows should be fully shaded. In the overheated period, the outdoor temperature is equal to or higher than the lower limit of the comfort temperature; thus, windows should be fully shaded. Additionally, the intensity of solar radiation varies with latitude and, generally, tropical regions (areas close to the equator) are the most susceptible to intense solar radiation (Koenigsberger et al, 1974). Consequently, in tropical climates, the horizontal surface is exposed to the highest intensity and the overheated period usually constitutes the whole year. However, as sunshine occurs in the daytime, shading design is essential in the day. Szokolay (1980) states that for opaque surfaces such as walls, solar heat gain is controlled by the thermal properties (absorbance and conductance) of the surface itself. Furthermore, north and south walls are exposed to the least intense solar radiation for short intervals during the year. However, walls facing the east and west are exposed to the second highest intensities. For windows (transparent surfaces), solar heat gain is controlled by the glass type and quality, internal blinds and curtains, and external shading elements.

According to Szokolay (2014), there are three categories of shading devices:

- Vertical devices such as vertical louvres or projecting fins;
- Horizontal devices such as horizontal canopies, louvres or projecting eaves;
- Egg-crate devices such as concrete-block or metal grilles.

The above considerations may be said to encapsulate principles of climatic design. According to Szokolay (1980; 2014), climatic design can be defined as the design of a building's passive controls to suit its contextual climate. Therefore, the objectives of climatic design:

1. For uncomfortable cold conditions include:
    a. to avoid heat loss;
    b. to take advantage of heat gain from the sun and internal causes.
2. For uncomfortable hot conditions include:
    a. to avoid heat gain;
    b. to encourage heat dissipation.

Additionally, when there are diurnal variations between hot and cold discomfort, climatic design aims to level the variations in both phases. Szokolay (1980) encourages designers to not replace good design with reliance on expensive and energy-intensive thermal control equipment. As such he mentions two approaches to climatic design:

1. qualitative approach,
2. quantitative approach.

Qualitative approach to climatic design

This approach involves making design decisions in relation to building massing, the building envelope's thermal properties, fenestration, provisions for ventilation and solar control at the conceptual design stage. Obviously, these decisions will depend on the climate type. The hot-humid climate is regarded as the most tasking climate to climatically design for. The diurnal variation in temperature is usually between 5 and 7°C and may be less in some conditions. Humidity levels are extremely elevated and evaporation from the skin is inhibited. Protection from rain, heat, humidity and insolation (exposure to solar radiation) is necessary. The main control of ventilation and cooling facilitate this protection. Szokolay (1980) states that designers should ensure that the indoor thermal conditions are not worse than outdoor conditions. The main cause of the heat is the extreme solar radiation which falls on the roof. The heat may be minimised by ventilation but the mean radiant temperature would have been increased. Regarding thermal comfort the mean radiant temperature is twice as significant as the air temperature. Therefore, the roof is the most challenging building envelope component in hot-humid climates. The possible and typical design guides recommended for the hot-humid roof include:

1. the combined U-value of the roof-ceiling assembly should be about 0.8W/m^{2}K to ensure that the ceiling temperature is higher than the ambient temperature by no more than 4°C;
2. a reflective roof surface or cover should be used;
3. the roof space should be well-ventilated to remove convective heat transfer between the roof and ceiling;

4. resistive insulating materials should be used;
5. reflective surfaces should be used under the roof and on top of the ceiling to reduce absorption and emission;

Other recommended design strategies include:

1. the use of lightweight building frames (such as timber) to facilitate quick cooling at night;
2. east and west walls should have reflective surfaces, resistive insulation and no openings to minimise the low angle sun;
3. most of the area of north and south walls should be open to allow maximum ventilation;
4. openings should be protected from the sun, mosquitoes, rain;
5. the building should be elevated to avoid ground level obstructions and high velocity gradient close to the ground; this effect is completely lost, however, in a dense settlement or where surrounding buildings are equally elevated.

Szokolay (1980) states that there is a new approach to passive design for the tropics. Based on the above recommendations, the passive design strategies propose a lightweight building raised on stilts. He refers to this as type as optimum for tropical suburban areas. However, in urban tropical settlements, elevating the building will not work. Therefore, the new school of thought recommends new passive techniques supplemented by active techniques such as the use of ceiling fans and air conditioning. One passive technique is placing the building on the ground using a concrete floor, where the ground acts as a heat sink. Thus with a massive external wall and floor, indoor day and night temperatures can be cooler in a closed heavyweight building than in a well-ventilated lightweight building. However, it should be noted that Szokolay (1980) states that this new massive arrangement is successful when used with active controls. According to Szokolay (2014), thermal mass, shading design, orientation and room use are significant for a free-running building.

Quantitative approach to climatic design

The quantitative approach to climatic design can be used through:

1. aligning or sizing the whole or components of the building thermal system to set performance criteria;
2. optimisation methods.

Performance criteria can include:

a. objective criteria such as thermal comfort limits;
b. statistical evidence such the daily hot water consumption for a family;

c. verified, accumulated professional knowledge.

Szokolay (1980) states that in sizing the design of a whole building to performance criteria, initial assumptions based on qualitative design decisions must be made. Then these assumptions are analysed and altered by quantitative investigation. He refers to the process as a 'trial-and-error' method. For instance, the thermal performance for a house may be guided by a criterion which specifies the limit of the indoor temperature. First initial and assumed qualitative design proposals must be made on the thermal system of the building. These can be checked by investigating the outdoor climatic parameters and deriving heat gains and losses in relation to the indoor temperatures. If the results from the check of the qualitative design show that the criterion has not been met, then the assumptions need modification (alteration of window sizes, changing wall material, increasing insulation and so on). Then, the new set of assumptions are checked again.

Optimisation is used when:

- "*…one design variable can be isolated;*
- *A dimension of this can varied either continuously or in discrete increments;*
- *A common measure of its cost and benefit can be found…*" (Ibid, p.336)

Accordingly, previous discussions indicate that the above principles have guided the design of traditional and colonial building envelopes, whose thermal performance has been commended. However, it appears that the implementation of these climatic design considerations has been diluted, due to the dependence on HVAC systems in tropical contemporary housing (Short, 2017). However, authors such as Short (2017) have begun to state that there needs to be a return to the implementation of climatic design principles. Consequently, the trend of supplementing contemporary envelopes with features of traditional envelopes mentioned earlier, has become very popular. This would reduce dependence on mechanical thermal control, which seems to be a major contribution to the current universal issue of climate change. Therefore, this leads to the question: will solving the problem of thermal discomfort in contemporary tropical housing equally solve the issue of climate change? This study attempts to answer this question in the next chapter.

2.8 Conclusion

This chapter has introduced the larger research areas of this study: housing, tropical climates, building envelope design for thermal comfort. It has explored the concept of housing on the abstract and physical dimensions. It has focused on what housing means in the tropical climates, especially the intense warm-humid equatorial/hot-humid/humid tropical climates. Hence, the evolution of humid tropical housing responses in the light of sustainability and time have been investigated. Through this investigation, this chapter has attempted to establish that, in the tropics, climate has always been and continues to be, a primary consideration irrespective of the chronological period. The relationships between acceptable and comfortable indoor environments, tropical building envelopes and outdoor climate has been investigated through the discourse on tropical housing. Although the building envelope may be said to be a physical expression of social and cultural changes through time, its role in determining thermally comfortable indoor environments seems more pertinent presently. Therefore, this chapter has studied factors, principles and approaches to climatic design, which aims to produce optimally performing tropical building envelopes. Furthermore, it has stated that contemporary tropical house fabrics have been reported to foster uncomfortable indoor environments and contribute to climate change. Climate change is a current reality that presents a more serious debate than the natural need for cooling and/or dehumidification strategies in the tropics (Adunola, 2014). There is evidence that changes in climate have erupted in tropical regions which already feature high temperatures and humidity and uncomfortable living conditions for their inhabitants (UNEP, 2011). As chrono-socio-cultural catalysts have caused the evolution of tropical housing, tropical climate change raises questions about what future tropical climatic conditions and housing responses might be.

Chapter 3

Climate change and Housing in Warm-Humid Climates - Introducing South-Western Nigeria

"We shall need a substantially new way of thinking if humanity is to survive."
Albert Einstein, 1954

3.0 Introduction

Climate change is a current universal buzzword; awareness about the concept of climate change seems to be increasing daily. Changes in world climates have manifested through increasing global temperatures, rising sea levels and melting glaciers among other signs. So far, the effects of these phenomena have endangered and continue to threaten human and terrestrial systems. Hence, there is a huge amount of attention on the causes and impacts of this variability in world climates. Many players, including those from architecture, have become involved in the investigations into the management and predictions of climate variability in different regions across the world. A key region of interest is the Tropics, where it has been established that the vulnerability of human and terrestrial systems is higher than in other parts of the world (Griffiths, 2015). This chapter examines the meaning of climate change, tropical climate change and housing, and how these subjects are expressed in the context of south-west Nigeria.

3.1 The Big Picture – Climate Change

The present focus on climate change has given its meaning many robust definitions and interpretations. However, a simple approach to understanding what climate change means is to explore the meaning of the phrase's root word: 'climate'. The notion of climate is based on weather elements and patterns which directly affect human life and ecological structures. Weather elements such as precipitation, temperature, cloud, and humidity display patterns in intensity and timing (Baede, Ahlonsou, Ding & Schimel, n.d.). These patterns show in the atmosphere of a location and a long-time consistency in these patterns forms the climate. Moreover, the ecological, socio-cultural, and economic set-ups associated with a region depend on these patterns. Agriculture, for instance, features the dependence of the availability of certain produce on rainfall patterns (Thiele, 2013). On the other hand, certain places within an expansive geographic location are chosen by indigenes as premium settlement areas due to more favourable weather patterns than other places in the same location (UNEP, 2011). However, when deviations from these patterns occur, the already-established human and ecological systems begin to flounder (Ibid.). These deviations have been termed climate variability: "*variations in the mean state and other statistics (e.g. standard deviations or the occurrence of extreme events) of the climate on all temporal and spatial scales beyond that of individual weather events*…" (UNEP, 2011, p.4). Presently, such deviations and their impacts on global human and ecological systems, have become very evident. It is here that the notion of climate change begins.

Following these evidences, investigations into the causes of these changes in weather patterns have been undertaken. Research has revealed that the weather conditions of different locations, are controlled by larger global atmospheric processes and cycles. More specifically, the sun's energy controls these natural cycles, which include "*the carbon cycle and greenhouse effect, orbital cycles, ocean currents that distribute warmer and colder water around the globe, and atmosphere-ocean interactions that moderate temperature*…" (UNEP, 2011, p.11). Accordingly, it has become clear that these weather systems are very sensitive to the consequences of human activity. The greenhouse effect is tied to the most popular atmospheric changes noticed around the world (Şekercioğlu, Primack, & Wormworth, 2012; NASA, 2016; Besada & Sewankambo, 2009). Mitchell (1989, p.116) says the term 'greenhouse' refers to "*the atmospheric gases which are relatively transparent to solar radiation but which absorb long-wave radiation*…". These atmospheric gases include water vapour, carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (CFCs). Mitchell's study goes on to say that these gases absorb sun-generated heat from the Earth's surface, release it back to the Earth's surface and into outer space. However, NASA (2016) expatiates that an increase in these gases makes it 'a blanket over the earth' which stops heat received from the sun, from radiating from the Earth into space (see Figure 3.1). The result is a trapping of heat and higher temperatures on the Earth's surface, causing the well-known, related term: global warming (Jamaludin, Khamidi, Wahab & Klufallah, 2014).

The greenhouse effect has become identified as the major cause of changing climates around the world (Trewin, 2014) (see Figure 3.2). At the root of this cause is the human activity catalyst (UNEP, 2011; UNEP, 2009; Şekercioğlu, Primack, & Wormworth, 2012; Shaw, Colley & Connell, 2007). The increased burning of fossil fuels such as oil and coal, in the last two centuries, has resulted in higher amounts of carbon dioxide in the Earth's atmosphere (NASA, 2016). Furthermore, other human activities, such as deforestation for agriculture and industry, the production of certain chemicals and so on, facilitate the thickening of the greenhouse gas layer (UNEP, 2009). The 1996 IPCC report enumerates the sectors that contribute to GHG concentrations: residential, commercial, and institutional buildings, transport, industrial, energy supply, agricultural, forest, solid waste and disposal sectors. These will be discussed in greater detail as this chapter unfolds. The blanket of gases creates alternate global climates where the afore-mentioned deviations manifest. This is the current state of many global climates where the examples of these changes in weather patterns generally include higher temperatures which lead to expansion of deserts, drying out of water ways, and droughts (Thiele, 2013; Adedokun, 2014a). In addition, higher temperatures spur melting glaciers, which have contributed to rises in sea levels and subsequent flooding in coastal areas (Thiele, 2013; UNEP, 2011). The impacts of these changes include disturbances in ecological systems causing migration of fauna (Şekercioğlu, Primack, & Wormworth, 2012). Some habitats have begun to change; for instance, trees have begun to invade savanna areas, disrupting original modes of survival in those savannah areas (Corlett, 2014). Higher temperatures have been discovered to affect human health where heat waves have caused more death than before, in contemporary times (UNFCCC, 2007; UNEP, 2011). The afore-mentioned impacts of climate change merely scratch the surface; more effects of climate change are being discovered through current research. These will be discussed in greater depth later in the chapter.

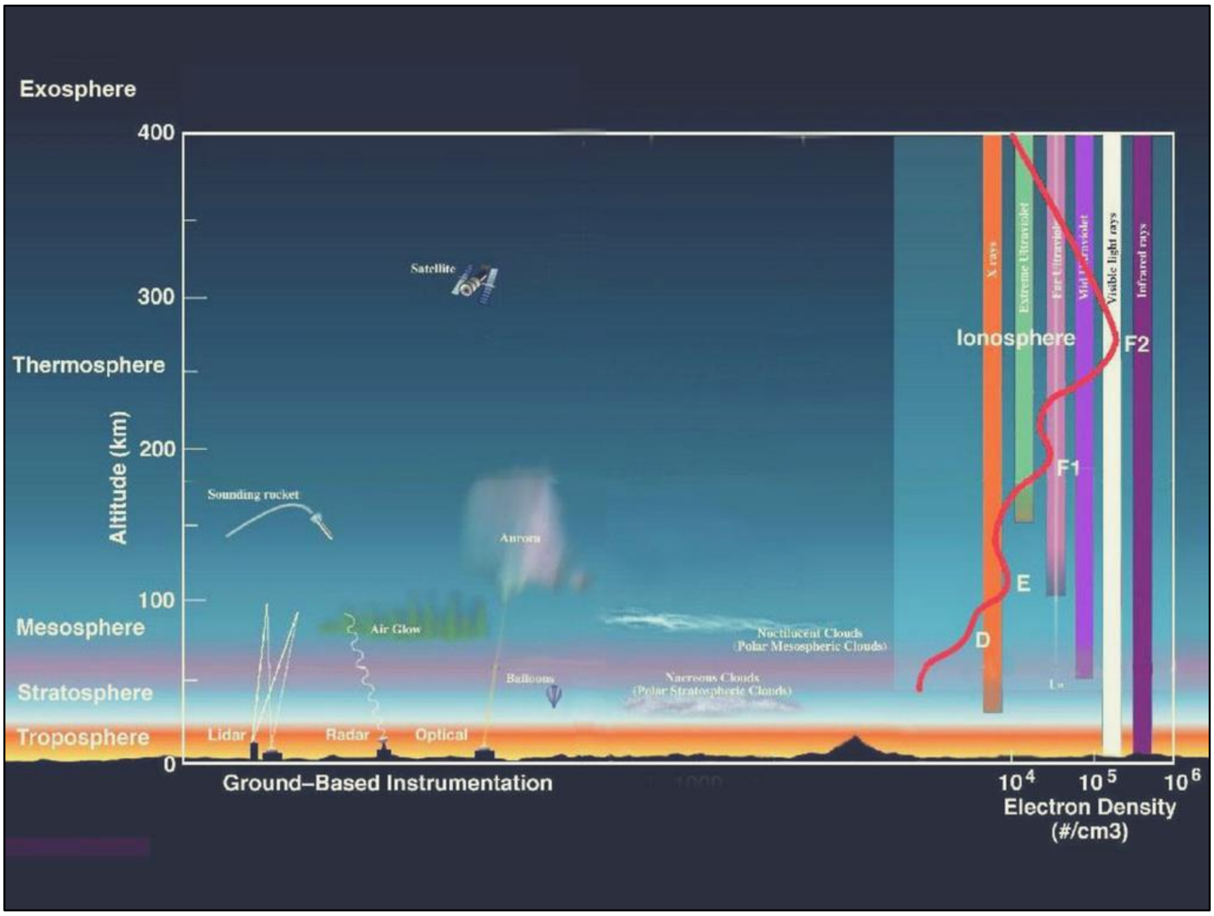


Figure 3.1 The different layers of the earth's atmosphere; source: NASA (2015).

Accordingly, the elements considered previously, summarily embody the concept of climate change. Despite the currently expanding entirety of this concept, established facts have created many simple definitions. The 2011 UNEP report (p.4) on climate change presents these definitions of climate change:

> *Climate change…refers to any change in climate over time, whether due to natural variability or as a result of human activity… climate change: a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to a natural climate variability observed over comparable time periods.*

The word 'change' is the most indicative term as far as definitions of climate change are concerned. However, there is an ominous streak to the effects of climate change on the present and future (Corlett, 2014). It is here that researchers have identified the connection between climate change and sustainable development. Sustainability and sustainable development are concerned with meeting the needs of the present without compromising the survival of future generations. Climate change threatens life in the present and future (UNEP, 2011; Besada & Sewankambo, 2009). However, Shaw, Colley & Connell (2007) argue that climate change is more of a current issue than a future one. However, predictions have revealed the massive potential of increasing changes in climate as human societies evolve through time (UNEP, 2009). These predictions will be examined in greater depth and context as this chapter progresses. Hence, the relationship is an intriguing one as sustainable development is proving to be a solution to climate change.

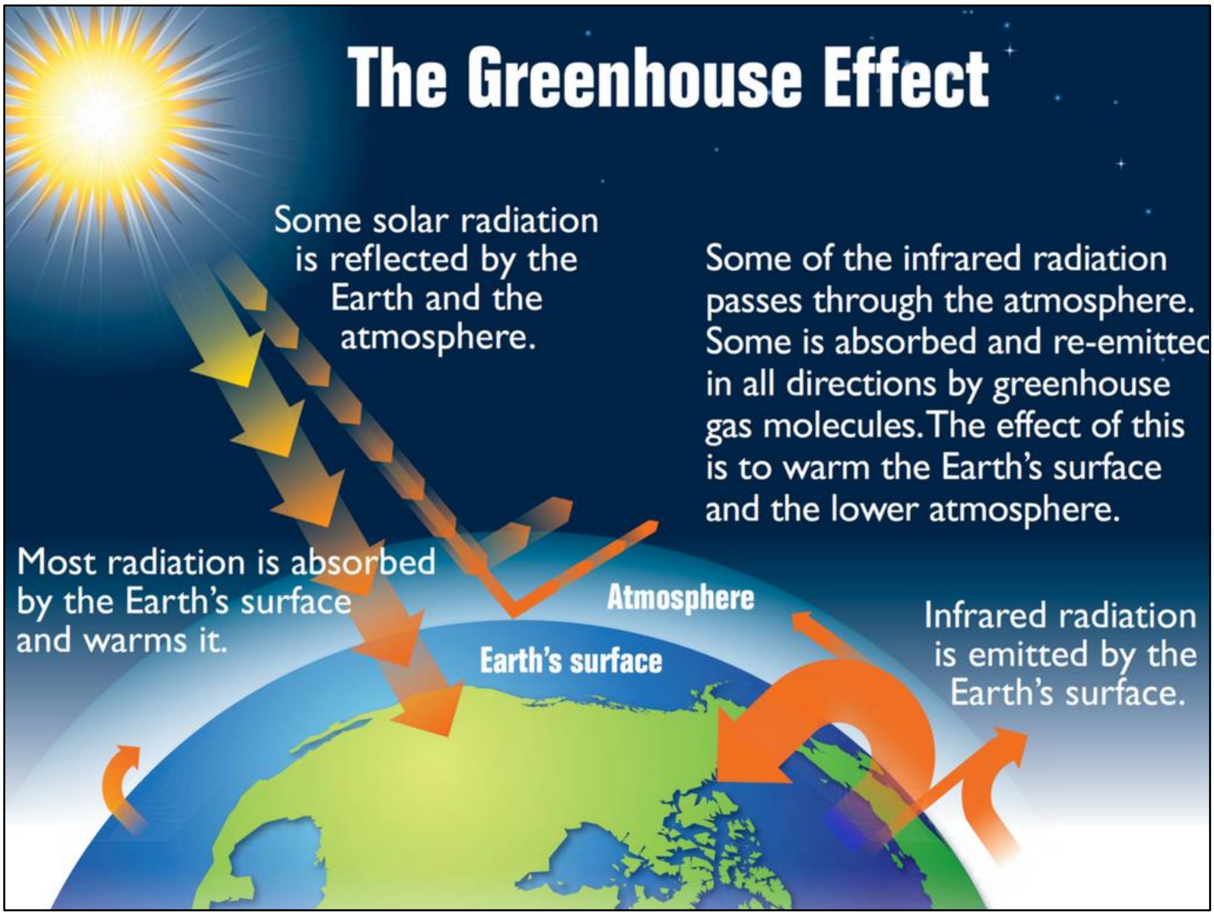


Figure 3.2 The Greenhouse effect; source: US EPA (2012, p.3).

Thus, climate change has been scrutinised from different angles in the light of sustainability (Jamaludin, et al 2014). The trifold nature of sustainability has pointed out the socio-economic dimension to climate change, in addition to its fundamental environmental element (Corlett, 2014). Investigating the socio-economic and environmental dimension of climate change sheds light on the relative ability of different countries in dealing with the features and impact of climate change (UNFCCC, 2007). These resources include technology, monetary funds, effective governance among others (Ibid). Therefore, it seems that the degree of resourcefulness of a region to deal with climate change, reflects its vulnerability to the phenomenon. Besada & Sewankambo (2009, p.32) expatiate that

> *Vulnerability to climate change has been characterised as a function of both exposure to climatic condition and the adaptive capacity of the population at risk. The vulnerability of populations to the possible impacts of climate change depends upon both the nature of the changes in natural systems and the nature of the human social, political, and economic systems in a given place at a given time.*

Vulnerability to climate change has proven very useful in the identification of regions most susceptible to climate change. Once again, this study's focus is drawn to the Tropics, which has been identified as the most vulnerable region to climate change on earth.

3.2 Rioting Rainforests – Climate Change in the Tropics

As stated in the last chapter, the Tropics are regions of the world where there is little or no seasonal, climatic variation throughout the year; the sun is directly overhead, leading to high temperatures, precipitation, and humidity levels (Koenigsberger, Ingersoll, Mayhew & Szokolay, 1974; Salmon, 1999). Commonly known as the tropical rainforest regions, they specifically include Africa, Asia, Australia, South America, and parts of North America (National Geographic Society, 2016). They make up 36% of the Earth's landmass, accommodating approximately one-third of the world's population (Ibid). Research has uncovered that the top ten countries at extreme risk from climate change are tropical countries (Martin, 2015). Consequently, the Tropics have received much attention on the issue of climate change.

According to Griffiths (2015), scientists state that the first signs of climate change occurred in the Tropics – specifically Africa, Australia and southeast Asia as far back as 1940. Drake (2014) adds that scientists had begun investigating world climates as early as the 1870s. They spotted the first signs of climate change in the afore-mentioned regions because their climates feature a small range of temperatures, as is typical with tropical climates. Hence, the increase in temperatures indicating the concept of global warming, were easily spotted. In addition, Sample (2016) affirms that the growth in the concentration of greenhouse gases (GHGs) began in 1830 with the Industrial Revolution. This caused the rise in temperatures in tropical oceans and the Arctic and half a century later the rises in temperature were substantive enough to be noticed. Hence, it has taken approximately two centuries for the effects of climate change to mature and the effects, though subtle at the beginning, are very glaring now (Ibid). In addition to exploring how far back these variabilities occurred, scientists are also very committed to investigating their causes. From the above discourse, it may seem that the major cause of climate change in the warm/hot humid regions is human activity. However, there are intricacies in the origins of tropical climate change that are worth analysing.

3.2.1 Causes of tropical climate change

Accordingly, human activity seems to be the most prominent facilitator of climate change in the tropics and it manifests itself in various forms (IPCC, 1996; UNEP, 2011) (see Figure 3.3). The earliest traces to the role of human activities in fostering climate change can be traced to the industrial revolution (Sample, 2016). Since that era, continuous technological advancement has spurred many developments which have been reported to contribute to climate change as well. However, this gives a general and succinct interpretation to humanity's role. There are different angles to the human climate change catalyst which may be summarised thus: built environments and production systems, land use changes, transportation, waste management and landfills (UNEP, 2011; UNFCCC, 2007). According to Thiele (2013), the built environment and production systems are elements and indicators of civilisation. However, people have used and continue to use up the Earth's resources to create these emblems of civilisation (Ibid; NASA, 2016). More specifically, energy is very relevant in the development of infrastructure and architecture, manufacture, and transportation in contemporary societies today. Most of this energy is generated through the combustion of fossil fuels (UNEP, 2009). Reserves of coal, oil and natural gas are processed to produce energy, the commodity of civilisation. However, these energy-production processes involve the refinement of ores and impurities are discarded as waste, most of which is gaseous (NASA, 2016; Mitchell, 1989). This gaseous waste is released into the atmosphere, thickening the greenhouse layer, and fostering global warming. It is only logical that an increase in the use of these processes will result in more gaseous waste that is detrimental to the atmosphere.

In the Tropics, rapid urbanisation and commercialisation has encouraged intense energy generation (UNEP, n.d.). Reserves of coal, oil and other minerals, which abound in these regions, are used up and processed to generate electricity and petrol-related products (Thiele, 2013). Gas flaring is the term used to describe the enormous release of gaseous waste from these production processes into the environment. In regions, such as Nigeria's Niger Delta, dark clouds illustrate the continuous gas flaring from the refinement of oil; studies have traced the increase in Nigerian temperatures to gas flaring in the Niger Delta (Cervigni, Rogers & Dvorak, 2013). It may seem that climate change is the cost of civilisation. Urbanisation has encouraged the use of vehicles for transportation in tropical cities and towns. Standard vehicles run on fossil fuels, such as petrol and diesel, and emit carbon dioxide among other greenhouse gases (Thiele, 2013; UNEP, 2011; UNEP, 2009; IPCC, 1996). Additionally, this element is compounded by the socio-economic factor of rural-urban migration, which results in overcrowded cities. Therefore, in tropical regions where socio-economic status holds social value, rural-urban migration is extreme, leading to overcrowded cities and an immense dependence on public and private vehicular transportation (UNEP, 2011; Bodach, Lang & Hamhaber, 2014). Hence, vehicular transportation is a notable contributor to climate change in the tropics.

Building construction is another element of societal development which has been identified as a contributor to tropical climate change. This is an especially striking and multi-faceted dimension of tropical climate change causation. The 2009 UNEP report states that all energy used in building construction originally comes from procedures involving the burning of fossil fuels. The report goes on to introduce the causative features of building construction at the construction stage. Energy generation starts when building construction procedures begin on site, creating induced energy. Moreover, the kind of materials used in contemporary construction in the tropics have been castigated based on their high environmental impact. Materials like cement and steel are criticised for their production processes which require extremely high temperatures and burning of fossil fuels (Butera, Adhikari & Aste, 2014). Hence, according to the 2009 UNEP report, the manufacture of a building material reflects the embodied energy it carries. Materials with high embodied energy or carbon pose high environmental impact, expediting climate change in the Tropics.

In addition, the transportation of these materials requires the use of vehicles which run on fossil fuels such as petrol and diesel. For grand projects, production plants may also be transported to construction sites. The 2009 UNEP report refers to this type of energy as grey energy. Furthermore, the report also states that operational energy is consumed in the operation of the building during its lifecycle. This generally implies the maintenance that goes on to sustain the building's capacity to function. The dominant problem of living in the Tropics is the intense heat. Hence, many buildings, whether residential, commercial, or industrial, are designed with cooling schemes. These involve mechanical set-ups and devices which depend on the energy generated by environmentally-unsafe procedures discussed above, and release additional waste in the atmosphere (Thiele, 2013). Here, the provision of energy for spatial functions is relevant. Biomass burning is a common household activity in tropical rural and sub-urban settlements

(Butera, Adhikari & Aste, 2014). The fire generated from burning biomass is used for heating, drying, lighting and cooking. However, the smoke released produces the greenhouse gas carbon dioxide (Ibid). The environmentally-unfriendly provision of energy for the spatial function takes a different form in the urban tropics, where the light and heat generated from biomass is replaced with electrical and gas-based lighting, heating, cooking, among others (UNEP, 2009). High population densities in tropical urban cities also compound this agent (Bodach, Lang & Hamhaber, 2014).

Finally, there is energy generated when the building is demolished and its parts recycled. Interestingly, there are debates as to whether recycling consumes or saves energy. Hutchinson's 2008 article reports the initial ridicule of the effectiveness of recycling at saving energy because recycling plants consume energy as well. On the other hand, recycling has obvious benefits, especially when it comes to recycling building materials. According to Hutchinson (2008), it requires 96% less energy to make aluminium from recycled cans than from its ore – bauxite. Still, recycling is now accepted as a mitigatory action against climate change. The higher the amount of energy consumed through processed based on the consumption of fossil fuels, the higher the amount of greenhouse gases released into the atmosphere. Accordingly, the amount of energy consumed by a building during its life cycle from construction to demolition, reflects its contribution to climate change. Unfortunately, it has been documented that for all reasons discussed before, most contemporary construction in the Tropics features high-energy buildings (Urge-Vorsatz, 2007).

Another popular human cause of tropical climate change is deforestation, which is usually connected to land use changes (Corlett, 2014; IPCC, 2016). According to the 2016 IPCC online report on land-use changes in the Tropics, the loss of tropical forests increased in the second half of the twentieth century. Trees were cut down, burnt, or left to rot, to provide raw materials for infrastructure such as rail roads and so on. The report also examines the relationship between deforestation and land-use changes. The driving forces of land-use changes include "*population, level of affluence, technology, political economy and structure, attitudes and values*" (Ibid). Considering this, population has been generally accepted as the major cause of deforestation. Research has revealed that when population increases, there is additional need for resources that can be produced through deforestation (UNEP, 2011). Furthermore, dramatic population growth can spur extreme migration which can lead to deforestation. Still the report presents the argument that the relationship between population growth does not always indicate the negative effects of deforestation. It cites an example where a population density increase in India, has resulted in more forest conservation. Hence, the report states that social structure is a major consideration when connecting population, land-use and deforestation. However, a focus on social structure leads to climate change mitigation in the tropics which will be discussed later. Accordingly, when trees are removed though deforestation, innate carbon dioxide is released into the atmosphere. This problem is further compounded because the trees, which absorb carbon dioxide from the atmosphere, are no longer there. Hence, the GHG blanket is thicker and global warming is stronger in the Tropics.

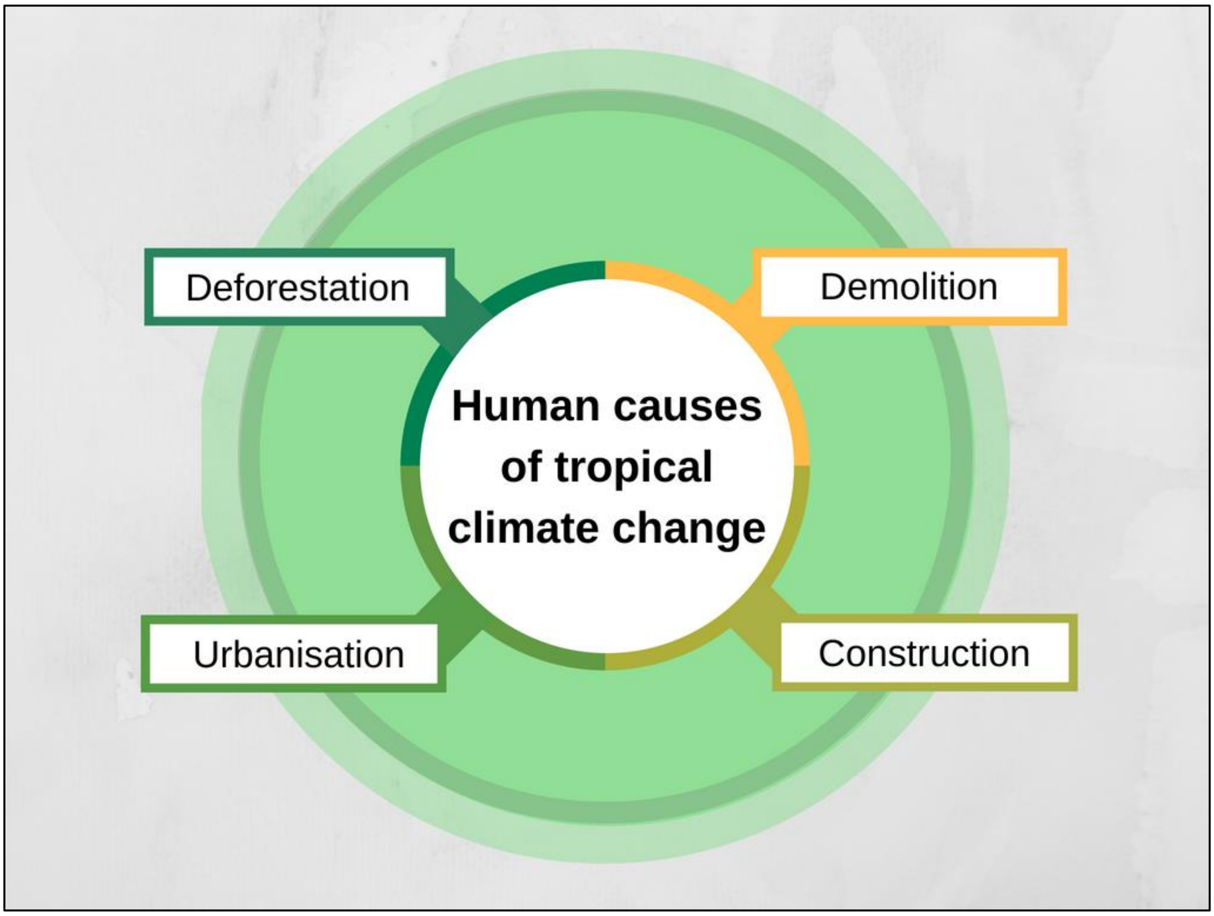


Figure 3.3 The causes of tropical climate change; source: author's study.

Correspondingly, human activities release atmospheric agents-greenhouse gases-that disrupt the natural make-up of the earth's climate. However, other atmospheric agents called aerosols have been identified (IPCC, 1996; IPCC, 1997). The Royal Meteorological Society (n.d.) gives a comprehensive description of aerosols on which the following information is based. Aerosols are distinguished from greenhouse gases because they are tiny solid or liquid particles which linger in the atmosphere. Their diameters range from a few nanometres to tens of microns and studies have revealed there are primary, secondary aerosols and organic aerosols. Primary aerosols are released as solid particles which include soot, dust and sea salt among others. On the other hand, secondary aerosols are produced, by chemical reactions in the atmosphere. Organic aerosols are emitted when chemical reactions act on chemicals released by organic matter such as plants. Furthermore, natural and man-made events create aerosols. Aerosols have natural origins when, for instance, volcanoes erupt (volcanic ash and sulphates), sandstorms occur in deserts and sea salts pervade the atmosphere through wind-driven sprays from ocean waves splash in the air.

Others occur from human activities such as soot from fossil fuel and biomass burning, and deforestation.

Aerosols "*influence climate by reflecting a portion of incoming solar energy back to space (direct effect) and in regulating the amount and optical properties of clouds (an indirect effect)* …" (IPCC, 1997). They also absorb infra-red radiation; this is true for dark coloured particles such as black carbon (Voiland, 2010). These actions create a cooling effect which seems the opposite to the climate change and global warming effect. However, this cooling effect creates a redistribution of heat which could cause variations in climate. Accordingly, Voiland (2010) states that aerosols cause climate change by their indirect effect of scattering light. Still, Voiland (2010) indicates the interesting ambivalence of aerosols as a contributor to climate change. Scientists believe that the cooling effect of aerosols seems stronger than their warming effect (IPCC, 1997). Furthermore, all aerosols which inhabit the Earth's troposphere are easily and quickly washed out by rain (Ibid; Royal Meteorological Society, n.d.). Hence, the amount of rainfall in a region is quite relevant in the concentration of aerosols in that region. Consequently, aerosols are passive actors in contributing to climate change in the Tropics where rainfall is high. GHG concentrations and their effects have been identified as the real drivers of tropical climate change (Şekercioğlu, Primack & Wormworth, 2012; Trewin, 2014).

The causes of tropical climate change have been and continue to be monitored. Scientists have come to understand that the causes of tropical climate change can be tracked through certain elements. These elements have made the variabilities in tropical climates obvious and continue to indicate the extent of climate change in the tropics. Hence, these elements are referred to as variables of tropical climate change as changes in their manifestations help to keep track of climate change in the Tropics.

3.2.2 Variables/indicators of tropical climate change

According to the 2007 UNFCCC climate change report, climatic variables of tropical climate change include temperature, rainfall and the frequency of extreme events such as floods, droughts, storm surges, cyclones (Corlett, 2014). In addition, non-climatic variables include "… *water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity and coastal zones* …" (UNFCCC, 2007, p.13). The UNFCCC report goes on to state that assessing these variables involves getting valid information on their statuses regularly. Therefore, different monitoring and assessment methods have been and are being developed and employed. Climatic variables are traditionally monitored from national meteorological stations but with the advent of climate change more specialised stations and methods are also being utilised. A very popular contemporary method used in monitoring climatic variables is the climate model which will be elaborated on later (IPCC, 1997). These stations monitor the major variables of ambient and sea surface temperatures, rainfall, sea level rise, wind speeds, tropical cyclones which include hurricanes and typhoons (Ibid). However, research has revealed that regional climatic variabilities in the tropics are tied to the El Niño Southern Oscillation (ENSO) phenomenon (Trewin, 2014).

The El Niño phenomenon features the ocean temperature changes in the eastern and central equatorial Pacific Ocean (see Figure 3.4). The usual cool temperatures of these waters rise during the ENSO, creating weaker equatorial trade winds, which affect global weather patterns. In the Tropics, the ENSO causes higher risks of dryness specifically in the western Pacific, eastern Australia, southern Africa, most of the Indian sub-continent and northeast Brazil, while East Africa and south-west America suffer increase in rainfall (Trewin, 2014). Furthermore, scientists have revealed that the ENSO is responsible for the most recent and warmest year (1998) in the Tropics and maintain that most of the event’s effect on temperature and rainfall is received in these parts (Martin, 2015). The 2007 UNFCCC report expatiates that flooding and drought in the Tropics, are directly linked to the ENSO. Consequently, the ENSO is being closely monitored and numerous predictions on future climates, which will be discussed later, are being derived.

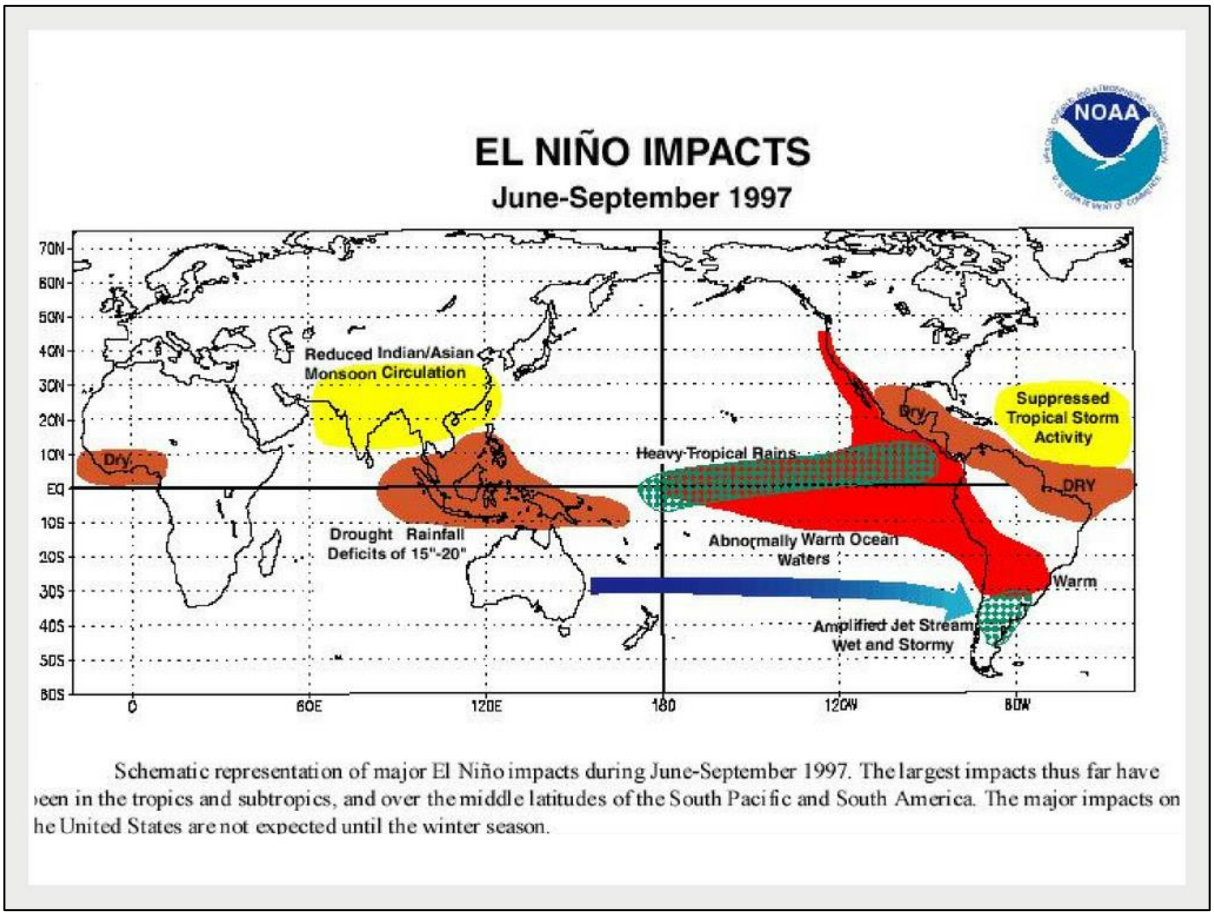


Figure 3.4 The El Niño phenomenon and its effects on global tropical regions; source: NOAA (1997).

Apart from the apparent focus on the ENSO event, many other intricacies exist in the monitoring of tropical climate change variables. The afore-mentioned climate models have proven extremely useful in tracking climatic variables. The 1997 IPCC report defines the climate model as a computer program formed of mathematical processes that incorporate enough components of the climate system, making it useful enough to simulate the climate. Climates models are tools that monitor present climates and predict future climate scenarios (UNFCCC, 2007; IPCC, 1997). These models take feedback from ecosystems into consideration in order to produce data as valid and realistic as possible. In addition, these models have led to the development of software that generate past, present and future weather data sets used in contemporary climate change research. However, Corlett (2014) castigates climate models by claiming that their future climate predictions are largely based on uncertainties. On the other hand, the 2007 UNFCCC report mentions regional workshops which have been organised to build capacity in tropical communities, in watching climate variables in their localities. Furthermore, the report reveals that these workshops have been criticised for not including methods of surveying non-climatic data.

Non-climatic variables, mentioned above, have been referred to as socio-economic and ecological variables. These variables can be said to indicate the vulnerability of the Tropics and reflect the impact of climate change in these communities. For instance, poverty in tropical regions inhibits their capacity to monitor climatic and non-climatic variables using the required systems. In fact, tropical socio-economic variables may also be said to influence climate change as economic growth leads to urbanisation and more technological GHG-generating processes (Corlett, 2014; Thiele, 2013). However, there is a basic, directly proportional relationship between the climatic and non-climatic variables in tropical climate change. The 2007 UNFCCC report (p.8) gives specific examples:

> *Changes in rainfall pattern are likely to lead to severe water shortages and/or flooding… Rising temperatures will cause shifts in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever. Temperature increases will potentially severely increase rates of extinction for many habitats and species (up to 30 per cent with a 2°C rise in temperature).*

Non-climatic variables are more relatable and directly involved in day-to-day living than their ethereal climatic counterparts (Martin, 2015). Therefore, it seems that changes in non-climatic elements are easily observed by members of a community than the technicalities of climatic variables which require more specialist knowledge (IPCC, n.d.). However, Corlett (2014) argues that the non-climatic variables of climate change which show as societal woes, seems to be more difficult to detect. He maintains that this is because human problems can usually be traced to various causes, and even causal chains. Still, it may be said that monitoring the climatic variables provides a bird's eye view of tropical climate change while monitoring socio-economic and terrestrial sectors provided a worm's eye view. A combination of both points of view seems to provide an integrated approach to assessing the variables in tropical climate change (UNFCCC, 2007). The assessments of on-ground climate change variables supplement aerial surveys of atmospheric variables. It is no surprise, therefore, that all members of society are encouraged to participate more in monitoring socio-economic and ecological sectors. The 2007 UNFCCC report illustrates this by affirming that the running of courses and programmes to encourage capacity building and participation. This strategy, which demonstrates how non-climatic variables in climate change can assessed, also falls under tropical climate change mitigation which will be expanded on later.

Assessing the variables of tropical climate change point to the impacts of tropical climate change. However, socio-economic and terrestrial variables seem to reveal how threatening the effects of tropical climate change are on life in the tropics.

3.2.3 Effects/Impacts of tropical climate change

Adedokun (2014a, p.10) provides a concise definition of the impacts of climate change: "*The impacts of climate change on the environment are actually the visible indicators or evidence of its existence in any locality* …". According to Martin (2015), it is the inhabitants of tropical areas that suffer the effects of climate change most among all the regions of the world. Martin (2015) also reveals that the top ten countries that are at extreme risk from climate change are all tropical countries: "*Bangladesh, Sierra Leone, South Sudan, Nigeria, Chad, Haiti, Ethiopia, the Philippines, the Central African Republic, and Eritrea* …". There are so many reasons why the people of the Tropics are more susceptible to the impacts of climate change. Many scientists believe that the major reason is life patterns of people in tropical climates have already been shaped around its natural narrow temperature (Trewin, 2014). Therefore, any sudden changes in the temperature ranges will tend to have significant effects on tropical lifestyles and ecosystems (Martin, 2015). In addition, Thiele (2013) affirms that the effects of tropical climate change are aggravated by "… *poverty, poor policy and institutional framework* …", features already attributed to many tropical countries. The impacts of tropical climate change are extremely varied but they can be classified into the following major areas.

1. **Natural disasters and drought**

Temperature changes in the tropical oceans lead to changes in trade winds. Consequently, hurricanes, typhoons and tropical cyclones populate the tropics, especially coastal areas more than before (Corlett, 2014). Rises in sea levels create storm surges and flooding, once again, in tropical coastal regions. Trewin (2014) also attributes flooding to the substantial increases in tropical rainfall. The alterations in the tides and winds due to climate change cause serious threats, specifically for tropical coastal settlements and island nations (UNEP, 2011). Reports on the destruction of coastal cities due to the overflow of surrounding seas have become very frequent (Ibid). Beyond the flooding of these areas are other related effects which include erosion, landslides and permanent inundation. On the other hand, tropical inland cities suffer increased risks of droughts which jeopardise agriculture and water resources. Şekercioğlu, Primack, & Wormworth, (2012) believe that the possibilities of these environmental hazards increasing in the Tropics, is high. Even more, these natural threats have been discovered to contribute to public health and disease.

2. Public Health and Disease

Scientists have discovered that the warmer temperatures and higher temperatures encourage the pathology of tropical diseases such as malaria and dengue fever (Martin, 2015) (see Figure 3.5). There is a focus on the increase of mosquito populations, and the consequent spread of malaria and other diseases carried by mosquitoes, to tropical highland areas with cooler climates which do not support the malaria parasite's lifecycle (Ibid; Corlett, 2014). The 2007 UNFCCC report describes the afore-mentioned diseases as climate-sensitive. On the other hand, the 2011 UNEP report also links potentials of epidemics in the tropics to urbanisation, a well-known facilitator of tropical climate change. As stated earlier, the connection between this class of the impacts and the first one is evident in the increase of water borne diseases due to elevated flooding and rainfall (UNEP, 2011). However, Urge-Vorsatz (2007) cites other types of diseases, such as respiratory and pulmonary diseases, due to biomass and fossil fuel burning in the Tropics. Furthermore, there are reports of more intense heat strokes claiming the lives of people due to the heat waves generated by higher temperatures (Lawal & Ojo, 2011). The climatic temperature element is connected to thermal indoor climates (Schumacher, Wortel & Wieringa, 2001; Adunola, 2014). Hence, higher outdoor temperatures mean higher indoor temperatures and a lack of comfort for building occupants. This disrupts social and environmental well-being in tropical housing. This impact, as well as the first one, operate at a smaller scale than the next two impacts of tropical climate change.

3. Political Instability and Conflict

This impact is largely speculative; however, Martin (2015) states that political unrest and corruption are more rampant in the Tropics than in other parts of the world. He further states that tropical climate change is expected to escalate in the coming decades, resulting in more conflict, stress and unrest in tropical

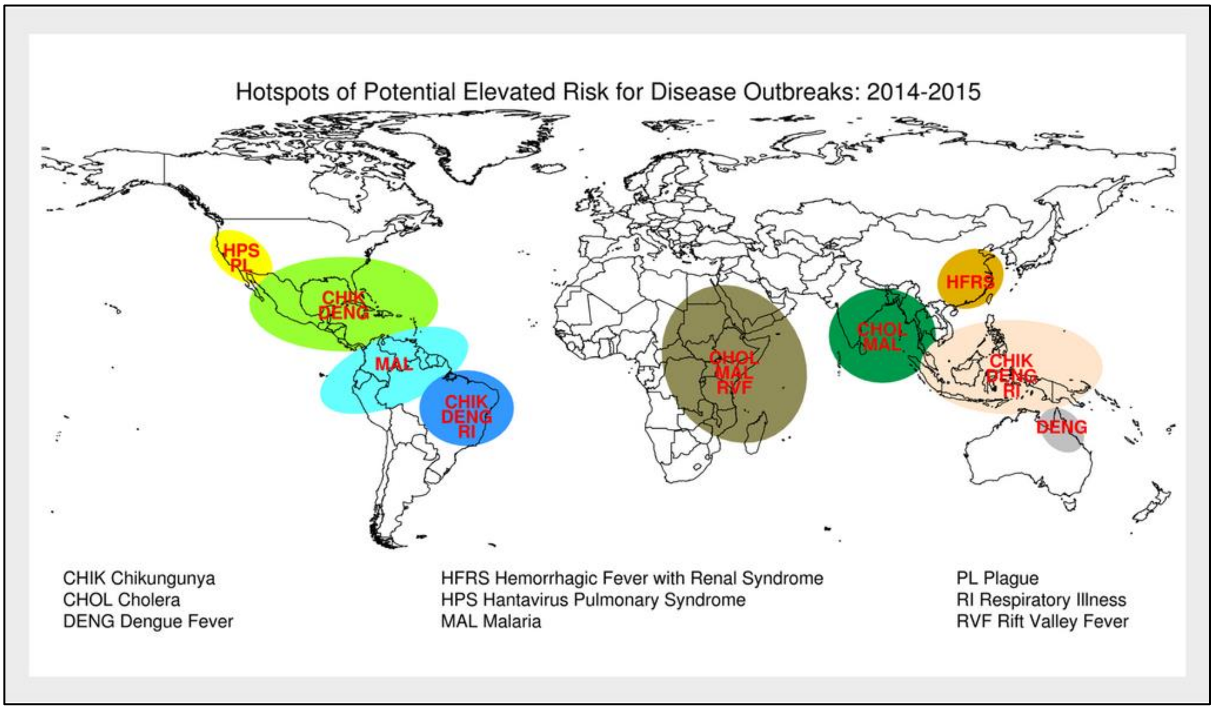


Figure 3.5 Impacts of climate change on health in the tropics; source: Chretien et al (2015).

societies. The main concern is that the politically unstable governments in the Tropics, are less likely to have the capacity to cope with these threats (IPCC, n.d). Consequently, inhabitants of tropical regions are expected to suffer climate change impacts more severely than those in the temperate regions of North America, Asia and Europe. More specifically, changes in tropical climate encourage migration and deterioration of farmland, which can result in inter-tribal conflicts (EPA, 2016). Moreover, infrastructural damages (due to natural disasters), food and water scarcity, population displacements are features of political instability induced by climate change in tropical regions (Ibid). It may be said that tropical political instability due to climate change, is facilitated by the impact of climate change on economics and agriculture in the tropics (Jamaludin, et al, 2014).

4. Economics and Agriculture

Agriculture has clearly suffered from the direct effects of tropical climate change. Martin (2015) says "...*farming is more vulnerable to climate change than almost any other livelihood, because of drought, flooding, crop disease and other effects. And more people make their living off the land in the tropics than in any other region*." Changes in climate have already begun to take their toll on agricultural practices in the tropics. Areas that have started facing severe climate change-induced droughts, have also experienced severe declines in crop and livestock health and produce. The reduced rainfall and higher degrees of evaporation lessen the amount of natural irrigation tropical crops usually enjoy (UNFCCC, 2007). Hence, tropical climate change threatens food security for inhabitants of the Tropics. Additionally, other sectors tied to agriculture will bear some transferred effects. According to UNEP (n.d.), food scarcity will foster malnutrition. The UNFCCC 2007 report explains that temperature increases cause the shift of crop rearing seasons resulting in disruptions in traditional harvest times and food scarcity. However, Corlett (2014) remarks that tropical highland agriculture can benefit from higher temperatures and rainfall because potential food production would increase.

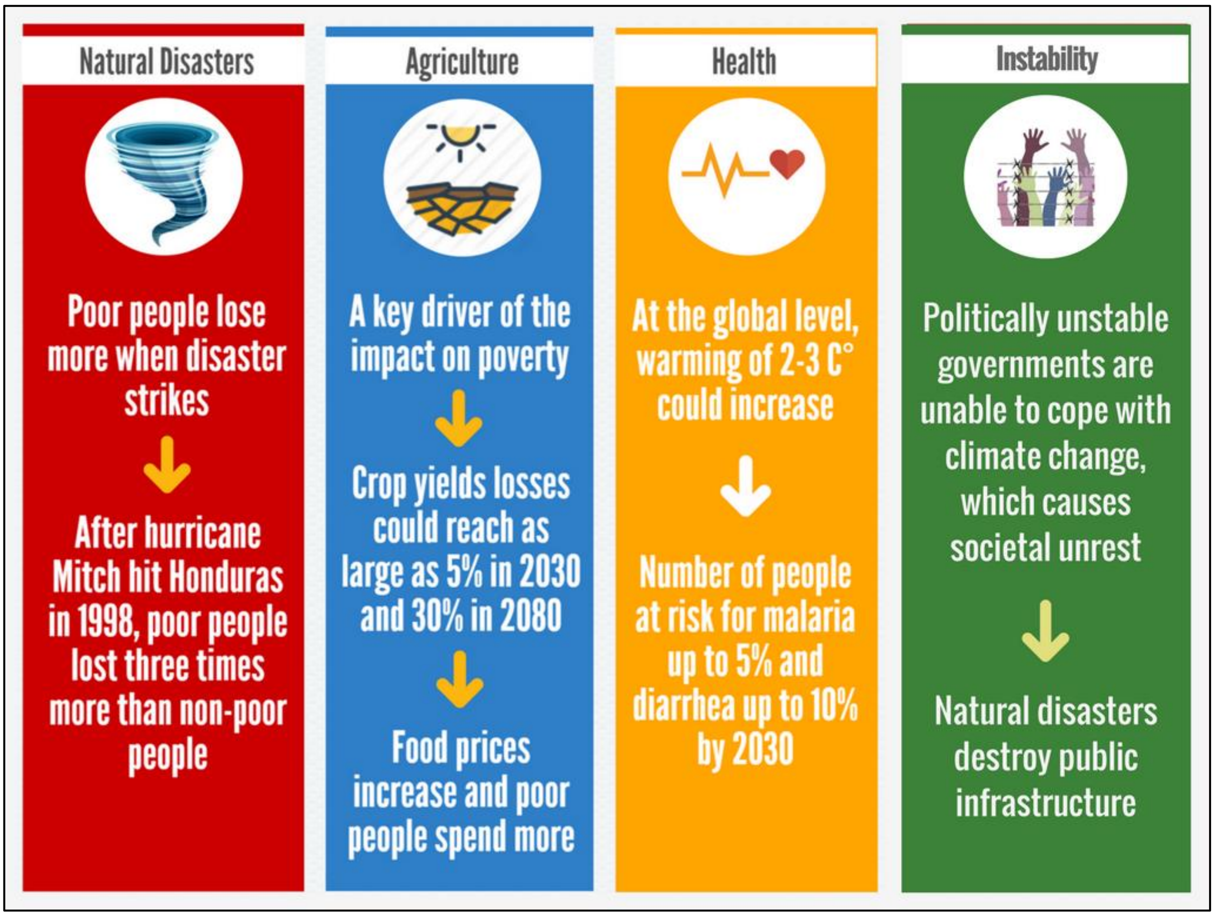


Figure 3.6 Impacts of climate change in the tropics; source: based on infographic by World Economic Forum (2017).

Furthermore, agricultural produce is a major lifeblood of many tropical economies (EPA, 2016). Declines in agricultural produce can create major dents in economic structure. Many tropical countries export agricultural produce to generate national revenue. With climate change interfering in the production cycles of these produce, tropical economies suffer loss of revenue. Authors such as Thiele (2013) demonstrate the unique dynamic between economy and climate change, which manifests in the tropics. As discussed earlier, production processes in the energy sector intended to encourage economic growth contribute to climate change. Then the agricultural sector suffers due to climatic variations and the economy deteriorates, causing and worsening poverty in tropical regions (Shaw, Colley & Connell, 2007). Destruction of infrastructure by natural disasters contributes to the decline of economy in many vulnerable tropical regions (EPA, 2016).

The four sections above highlight the general impacts of tropical climate change, summarised in Figure 3.6. Nonetheless, it is useful to know what entities are on the receiving end of these impacts. It is evident that biological, ecological, and socio-economic systems endure the most of these impacts. Still, for better clarity, the following paragraphs will analyse and investigate how climate change impacts are received in the tropics.

3.2.4 Recipients of tropical climate change

Scientists have revealed that there are two main structures that suffer the effects of climate change – human and natural systems (Corlett, 2014; Thiele, 2013; UNEP, 2011; Jamaludin, et al, 2014). In the Tropics, human systems suffer climate change in different spheres and at different levels, which will be elaborated on later (Corlett, 2014). The effects of tropical climate change on natural systems can be studied in terms of variations spawned and their accompanying implications on ecological setups (UNEP, 2011; Şekercioğlu, Primack, & Wormworth, 2012). There are many interconnections between both systems as they respond to climate change (Corlett, 2014). However, it may be said that the dual nature of the human system as a causative and receptive agent of climate change shows the significance of humanity's role in climate change creation (Shaw, Colley & Connell, 2007; Thiele, 2013). Natural systems are mainly recipients, exhibiting patterns that have contributed to the climate change theories proposed by scientists today.

Research has placed a large amount of attention on the vulnerability of ecological systems to climate change. Ecology embodies the way plants and animals exist in relation to one another and their environment (Miller & Spoolman, 2009). Accordingly, the focus here is the relationship between plants and animals and their environment. Climate is an element of ecosystems (terrestrial and marine) (Ibid); the influences of climate change are seen in seasonal cycles which govern the life cycles of flora and fauna. In the Tropics, the melting of glaciers on mountain tops is the most common response of terrestrial systems to climate change. Thiele (2013) and the IPCC (n.d.) assert that the absence of these glaciers is responsible for subsequent droughts. On the other hand, tropical marine systems feature coral reef bleaching due to rising sea temperatures. Nevertheless, Corlett (2014) reports that melting mountain ice caps and coral reef bleaching are more validated responses to tropical climate change than the current droughts, floods, and cyclones. It seems that this claim is weak as many other researchers (Trewin, 2014; UNEP, 2011) have established a link between natural disasters and climate change in the tropics. Additionally, these changes in the structure of marine and terrestrial systems have resulted in the isolation and redistribution of plant and animal ecosystems. Many animal species migrate from inhospitable habitats in search of habitable ones (Şekercioğlu, Primack, & Wormworth, 2012). This response from flora and fauna spurs more reactions from human systems. However, there are many layers to the concept of human systems as recipients of climate change in the tropics.

Corlett (2014) maintains that human health reacts most significantly to climate change, even in the Tropics. During the warmest months of the year, the increase in temperatures have caused heat waves and subsequent deaths (Ibid). This clearly demonstrates the human reaction to climate change in tropical regions. Human health also responds to the effects of natural disaster impacts (UNEP, 2011; Besada & Sewankambo, 2009). As stated earlier, risks of epidemics caused by food- and water-borne diseases are higher due to tropical floods. Economically, people in the tropics experience a mix of reactions. Tropical lowlands are prone to suffer the negative impacts of climate change, as temperature rises do not suit crops (Corlett, 2014). Subsequently, food scarcity will mean a decline in economy. On the other hand, agriculture and, subsequently, the economy in tropical highlands, are predicted to benefit from higher temperatures. However, people living in tropical highlands seem more predisposed to negative health impacts as earlier stated (UNEP, 2011). Furthermore, inland settlements experience the effects of climate change tied to public health and conflict, economy, and agriculture. It is the coastal regions which have a double dose, suffering natural disasters in addition to the other impacts. In terms of socio-eco-cultural classification, tropical urban, suburban, and rural settlements experience these health and economic reactions. Still, it can be said that as poverty levels are lower in urban cities than in rural areas, urban dwellers may be better equipped to cope as recipients of climate change than the latter. Most of the additional forms of reactions people living in the Tropics are predicted and speculative (Nigeria. Ministry of Environment, 2003). These include competition for food and water or intense climatic phenomena. Accordingly, human systems or societal sectors as recipients of climate change have initiated ideas on how to manage the accompanying effects. It is here that the concepts of adaptation and mitigation come up; these can be termed the responses to tropical climate change (Nigeria. Federal Ministry of Environment, 2010).

3.2.5 Responses to tropical climate change

The responses to tropical climate change encompass climate change adaptation and mitigation and its foremost players. It is obvious that people as recipients of climate change impacts, need to protect themselves from the negative impacts and explore ways of curbing climate change. With the development of this awareness, certain bodies have been established to undertake the responsibilities of initiating, organising, and implementing responses to climate change. The most popular of these are the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) (UNEP, 2011; Shaw, Colley & Connell, 2007). These bodies have generated tremendous amounts of research on climate change worldwide.

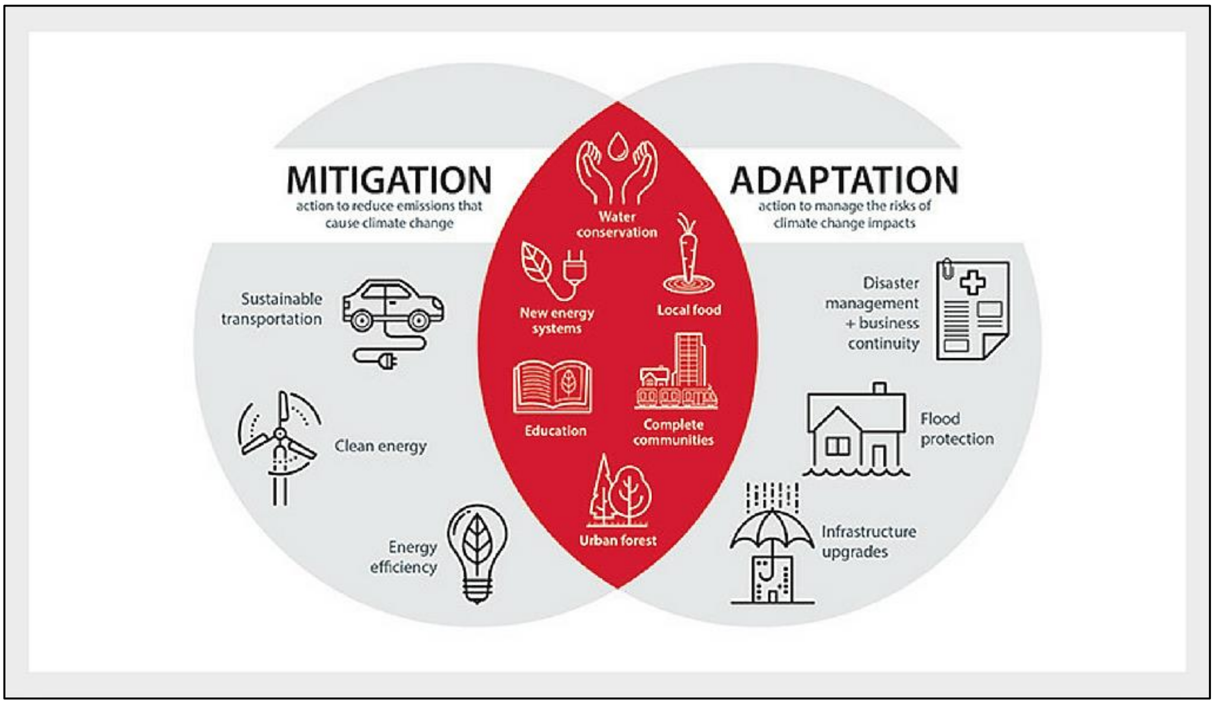


Figure 3.7 The two main responses to climate change in the Tropics; source: Calgary (2017).

The UNFCCC primarily "…*provides the basis for concerted international action to mitigate climate change and to adapt to its impacts. Its provisions are far-sighted, innovative and firmly embedded in the concept of sustainable development…*" (UNFCCC, 2007, p.10). This player organises workshops, conferences and meetings to facilitate appropriate climate change responses at different levels in various regions. Additionally, it fosters climate research and observation schemes, encouraging the collation of meteorological data and investigating capacities to predict future climate scenarios (UNEP, 2009). In this way, the UNFCCC is a major pusher of climate change adaptation (UNEP, 2011). On the other hand, the IPCC provides climate change assessment tools, models and methodologies. It is also involved in climate change prediction, creating future climate scenarios necessary for adaptation (Ibid). Other independent and region-specific players in the battle against climate change have based their work on that of the UNFCCC and IPCC, and partner with them. An example is the Kyoto Protocol, established to govern GHG emissions and aid in climate change adaptation by developing countries (UNEP, n.d.; UNFCCC, 2007). However, with an increasing focus on the most vulnerable Tropics, the Conference of the Parties, which governs international conventions, have petitioned the UNFCCC to focus on climate change in Africa, Asia, Latin America, and some developing islands (UNFCCC, 2007). Concurrently, the IPCC has executed extensive work in tropical climate change, especially the African state (Corlett, 2014; Trewin, 2014). These players bring climate change adaptation and mitigation to life.

Climate change mitigation is focused on reducing greenhouse gas emission by encouraging lower carbon living (Thiele, 2013; Shaw, Colley & Connell, 2007). Mitigation is aimed at finding ways of stopping climate change, by focusing on the main causes-GHG emissions (Corlett, 2014). In the Tropics, mitigation is being implemented in different ways and at various levels. Most mitigation policies are created at the international level by the major players, such as the UNFCCC and IPCC. National governments are expected to adopt and enforce these approaches in their respective countries. Policies have been and are being developed to govern activities in the major human societal sectors-building, transport, industrial, energy supply, agricultural, forest, solid waste and disposal-that contribute to climate change. These policies cover different areas, such as meteorological and socio-economic data collection, awareness and capacity building and the protection of ecosystems among others (Şekercioğlu, Primack, & Wormworth, 2012). However, it seems that the intentions of climate change mitigation at the international and national levels have been lost in politics; local governments and private establishments have had more successful mitigation by encouraging small-medium scale low-carbon schemes (Corlett, 2014). Therefore, climate change mitigation is not as effective as it can be in the Tropics.

Nevertheless, concepts on tropical climate change mitigation are being explored. In the agricultural and energy supply sector, biofuel crops were introduced as an innovative tool (Ibid). Biofuel crops reduce carbon emissions because the carbon dioxide given off while burning them for energy-generation is absorbed during their growth. Hence, they are a double-benefit option – climate change mitigation and economic growth. The effectiveness of biofuels, however, has been challenged by land use conflicts (Ibid). It seems that for biofuels to be a competent mitigation tool, better land-use management and technologies that use a wider range of plant materials must be effected simultaneously. Additionally, vehicles that are fuelled by materials other than fossil fuels are being promoted in the Tropics, as mitigation in the transport sector (Shindell, Faluvegi, Walsh, Anenberg, Dingenen, Muller, Austin, Koch & Milly, 2011). The decomposition of waste in landfills is generally a less popular contributor to climate change than others, in the Tropics. However, with the aggressive climate change counter, recycling is being promoted. Industries in the tropics are being encouraged to go with green manufacturing and afforestation programs have been engineered to replace eradicated ecosystems and trees that will absorb carbon dioxide (UNEP, 2011; Lee, 2013; Guariguata, Cornelius, Locatelli, Forner & Sanchez-Azofeifa, 2008). These examples show the various mitigation strategies being employed in the tropics. However, the role of the tropical residential building sector in climate change mitigation will be examined in-depth later.

Climate change adaptation, on the other hand, may be said to be more accepted and adopted as a counter-climate-change choice in the Tropics. UNEP (2011, p.52) states the UNFCCC definition of adaptation as "…*changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes*…" Unlike mitigation, adaptation is a passive response to climate change where the problems dictate the nature of the adaptive solution. Adaptation focuses on reducing climate change vulnerability rather than stopping climate change altogether (Corlett, 2014). Shaw, Colley & Connell (2007) assert that adaptation is the more appropriate response to climate change as climate is already changing and is predicted to continue to change. Their study emphasises that adaptation uncovers hidden benefits of climate change; for example, flood defences can promote biodiversity, climate-proofing by organisations can secure investments and reduce costs, among others. Interestingly, they also mention that adaptation might be double-edged, where adaptive strategies present opportunities which may create distractions from the original climate adaptation purposes.

Closely associated with adaptation is the concept of resilience; the capacity to adapt to climate change is directly proportional to resilience (Trewin, 2014; UNFCCC, 2007). Resilience implies a capacity to absorb and still thrive under climate change stresses. Resilience likewise means the capacity to adapt and readjust to beneficial settings in preparation of future climate changes (Nigeria. Federal Ministry of Environment, 2003). Accordingly, a main theme of adaptation is the consideration of future climate scenarios (UNEP, 2011; Corlett, 2014), rooted in the principles of sustainable development (UNFCCC, 2007). Hence, adaptation can be referred to as a sustainable approach against climate change; it curbs the potential of climate change to truncate the goals of sustainable development (Ibid). Adaptation is implemented per the nature of climate change impacts. As climate change has been and is being monitored, adaptation has been classified according to the occurrence of these impacts. The 2011 UNEP report gives a comprehensive explanation of the categories of adaptation. Anticipatory/Proactive adaptation is the kind that occurs before the effects of climate change are seen. Differently, reactive adaptation occurs after the climate change impact has happened. This type of adaptation is generated to the impact, starting after it has already manifested.

Planned adaptation is more efficient and cost-effective than reactive adaptation because the former involves careful and meditated reactions to climate and its changes. It seeks to reduce the damages of potential impacts and encourage long-term benefits while reactive adaptation deals with fixing immediate damages. Planned adaptation involves intentional policy-making in different sectors, founded on the knowledge of climate change and that steps must be taken towards restoring and maintaining or attaining the acceptable state. The development and application of planned adaptation schemes are indispensable in the active management of climate change risks. Additionally, planned adaptation schemes require assessment to make room for improvements in their implementation. The fourth type of adaptation may be said to be directly opposite to planned adaptation. Autonomous/spontaneous adaptation constitutes responses to climate change which are not intentional or conscious. This category of adaptation embodies the adjustments of natural and human systems, which are not controlled by meditated policies or plans, but prompted by ecological changes in natural systems and socio-economic changes in human systems.

In the Tropics, planned adaptation strategies are being cultivated for the different sectors, with future climate scenarios in mind. The 2007 UNFCCC report insinuates that the Tropics can adapt to climate change socially, technologically, and financially. Corlett (2014) emphasises the need to adapt agricultural practices to changing climates as this will determine future crop yields. New crop species, resistant to climate change, can be bred to live well in future climates. Flora and fauna are being aided in relocating to new ecosystems (Şekercioğlu, Primack, & Wormworth, 2012). The above strategies fit with technological adaptive potential which international, national and prominent public establishments have innate capacity to implement (UNFCCC, 2007). Social adaptive responses are better suited to small public organisations and individuals (Ibid). Behavioural changes (such as choice of clothing) and adjustments to living environments (such as the use of insecticides and mosquito nets) are examples of social responses. However, there has not been much success with enforcing these strategies, especially at the international and national levels, due to the same inhibitor of tropical climate change mitigation: politics, and additional ones: lack of funding, resources and institutional capacities.

The IPCC and UNFCCC estimate that developing countries will need billions of US dollars to effect climate change adaptation in future climate settings (Ibid). Adaptive financial responses govern large-scale adaptive projects and are usually the responsibility of international and national players – policy makers and stakeholders. It is here that the UNFCCC's Kyoto Protocol program steps in as it champions the Adaptation Fund for developing countries (Adaptation Fund, 2016). Nevertheless, the UNFCCC has orchestrated capacity-building and awareness campaigns at local levels to combat the inhibition of tropical climate change adaptation at the international and national levels (Ibid). These local workshops and conferences encourage the exploration of indigenous knowledge on communal survival through generations. In the words of the 2007 UNFCCC report (p.36),

> *There is a large body of knowledge and experience within local communities on coping with climatic variability and extreme weather events. Local communities have always aimed to adapt to variations in their climate. To do so, they have made preparations based on their resources and their knowledge accumulated through experience of past weather patterns. This includes times*

> *when they have also been forced to react to and recover from extreme events, such as floods, drought and hurricanes.*

Therefore, traditional knowledge is a repository of time-tested, cost-effective and context-specific adaptive strategies which can be easily employed by communities in adapting to climate change in the tropics. Traditional knowledge is a perfect representation of autonomous adaptation, offering solutions to climate change which highly needed currently. Workshops and conferences are also held at national and international levels. However, they are concerned with more scientific strategies such as collation of meteorological and socio-economic data as well as the utilisation of climate modelling and assessment as well as scenario analyses to understand tropical climate changes.

A dominant climate assessment and modelling player in the Tropics is the Global Climate Observing System (GCOS), which has proved very useful in developing Asian countries like China, Iran, Sri Lanka, Nepal and Uzbekistan. The GCOS is a systematic observation program which constitutes climatic monitoring, prediction and assessment. Such systems have generated historical, present and future weather data for tropical regions; this data is currently used in digital climate change modelling and research. The IPCC is especially involved in the aspect of climate change adaptation, as it provides similar assessment models, tools and methodologies to the provisions of the GCOS. The 2011 UNEP report also mentions Global Climate Models (GCMs) which it refers to as complex computer models and the primary tools for simulating past climates and predicting future climates. Yet Corlett (2014) expresses doubts in climate change models saying that their predictions are based on assumptions which might be unrealistic. It follows, therefore, that these predictions might not happen. Additionally, the UNFCCC believes that national climatic data provided by global climatic models might be too vague to suit the country's individual needs and do not represent human interactions and local adaptive potentials (UNFCCC, 2007). Nevertheless, these models form a huge part of planned adaptive strategies, which create sensitisation to and a safeguard against the destructive potentials of unsupervised climate change (UNEP, 2011; Besada & Sewankambo, 2009). Furthermore, according to the 2011 UNEP report, studies have shown that these models are able to provide reliable information on future climates and greenhouse gas emissions.

Future tropical climate scenarios have been created, especially for Africa (UNEP, n.d., Besada & Sewankambo, 2009). Scenarios have been defined as images of the future or alternate futures, which do not actually predict the future (Nigeria. Federal Ministry of Environment, 2003). The basic purpose of climate change scenarios is to investigate the highest number of possible ways to reduce GHG emissions (Ibid). Africa has been classed as the most vulnerable continent to tropical climate change (UNEP, 2011). These scenarios present predictions on the socio-economic and environmental states of natural and human systems in the coming decades – the rest of the 21st century. The UNEP report (n.d.) provides a comprehensive detailing of future scenarios in many sectors in Africa. However, as this study's attention is on housing, its focus is on the future state of tropical climate change regarding housing. As the nature of the external climate affects the indoor climate, information on the future predictions for the tropical climate are relevant at this point. According to the UNEP report (n.d.), by 2050,

- mean temperatures in Africa are predicted to rise by 1.5-3.0 °C and will continue rising beyond this period;
- annual precipitation is predicted to decrease by 4% in the West African tropical rainforest/hot-humid zones.

There are predictions that, by 2030, GHG emissions would be 40-110% higher that they were in 2000 (Ibid), with most of the increase starting in developing countries, which are mostly tropical. These predictions indicate a present and future that require planned adaptive actions if human society must survive and thrive (UNFCCC, 2007). The previous analyses have shown that these adaptive strategies are already being cultivated and enforced in various sectors in the tropics. However, this study focuses on the building sector.

Studies have shown that the building sector has much to offer with regards to climate change mitigation and adaptation in the tropics (Butera, Adhikari & Aste, 2014; Urge-Vorsatz, 2007; Thiele, 2013; UNEP, 2011). This is quite logical because the nature of the built environment influences health and well-being (Lawal & Ojo, 2011), which is impacted by climate change (Martin, 2015). Therefore, in the discipline of architecture, new themes linked to climate change have become standards governing the building design and construction, and this fact applies in the Tropics.

3.3 The Three-fold Cord - architecture, climate change mitigation and adaption in the tropics

Buildings are responsible for over 40% of global carbon dioxide emissions; building heating and cooling systems give off water vapour, which is also a GHG (Thiele, 2013). These are facts that show the potency of the architectural profession's role in the facilitation of climate change. Although most of the contributions to climate change arose from architecture in developed countries, it has been projected that architecture in developing tropical countries will contribute most to future climate variability (UNEP, n.d., Butera, Adhikari & Aste, 2014). This is not a far-fetched statement as increasing urbanisation in the developing world constitutes the construction of buildings with massive amounts of energy throughout their life-cycle (see section on causes of tropical climate change). Therefore, architects, as well as other specialists in

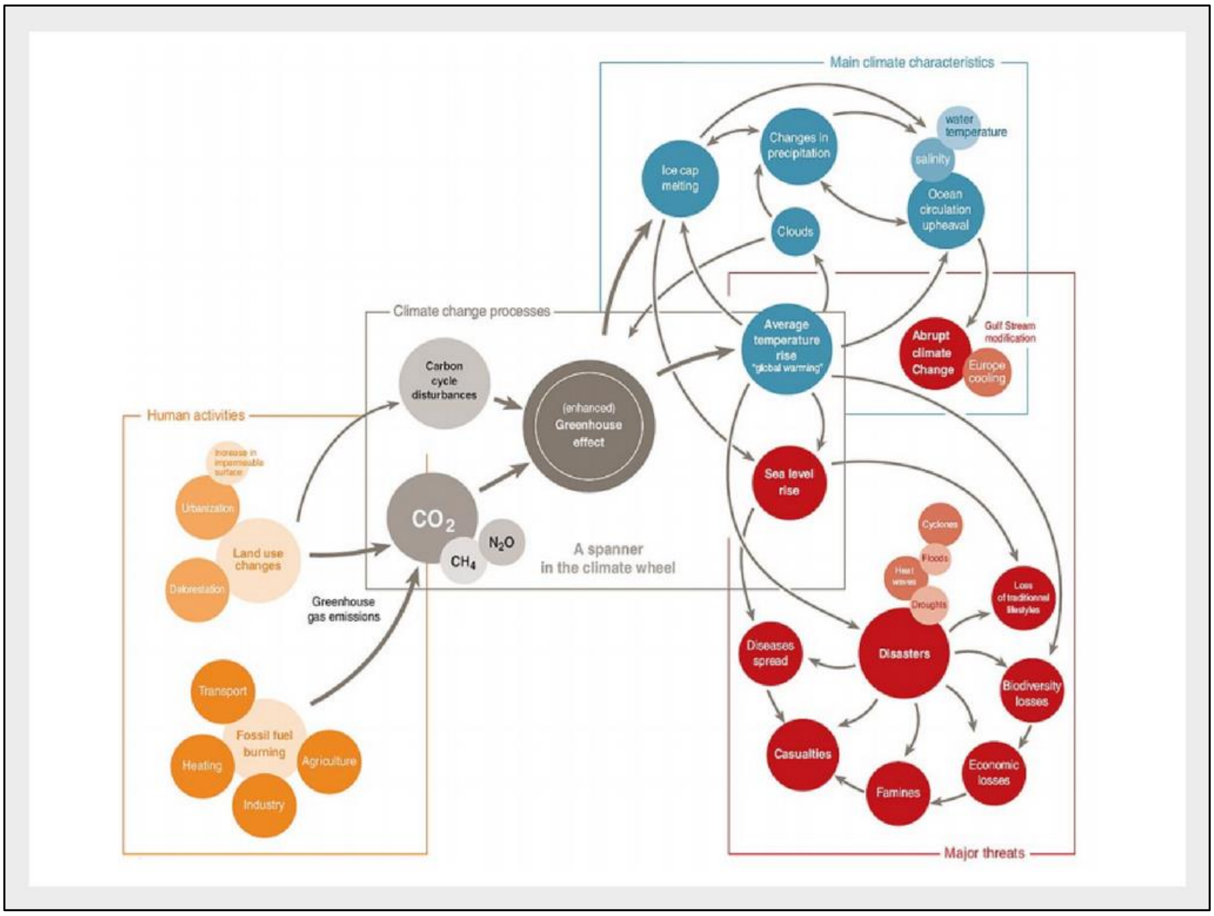


Figure 3.8 Relationships between the causes, indicators and impacts of climate change in the Tropics; source: Grid-Arendal (2018).

tropical building design, have been sensitised towards creating buildings that are low-energy (Tessema, Taipale & Bethge, 2009). This is one more trend in line with the sustainable development goals pursued internationally, and is increasingly becoming the norm in tropical architecture, especially tropical housing (Ibid).

Building designers have begun exploring ways through which of climate change mitigation and adaptation in housing. The UNFCCC has disclosed the role of housing in climate change adaptation (UNFCCC, 2007). It emphasises that improvement of environmental quality and change in urban and housing design would give better housing and living conditions while primarily adapting to climate change impacts on human health. Many tropical housing innovations aim to create an optimum blend of the physical and non-physical aspects of housing and are more adaptive than mitigatory (Ibid). These innovations tend to meet the needs of housing with technology that does not contribute to climate change. It can be inferred from previous discussions that in the tropical/hot-humid contemporary society, typical housing is a product of and functions with energy. Short (2017) says that contemporary buildings worldwide, are characterised by steel and concrete framing, lightweight internal materials, glazed skins, utility spaces in between floors and mechanical thermal control plants. Most energy used in construction arises from the production of these contemporary materials. Mechanical thermal control is the essential component of the artificial environments created by contemporary buildings. Short (2017) explains that air conditioning has become widely accepted because, as the previous chapter noted, it symbolised socio-economic growth. He claims '…*the aggressive marketing of artificial weather released the design of buildings from any need at all to be responsive to climate…'* (Ibid, p.4) Furthermore, mechanical thermal control consumes high amounts of energy and releases substantial amounts of carbon dioxide (Ibid). During the lifespan of the house, electrical energy is needed to run these mechanical thermal systems as well as other equipment such as domestic appliances.

This implies a high amount of energy necessary for housing, especially where cooling is a prominent need. Therefore, the core theme of common adaptive methods in housing, is energy-efficiency. Patterson (1996) defines energy-efficiency as the ratio of the useful output of a process to the energy input into a process. Thus, adaptive strategies in tropical housing, aim at providing housing and its corresponding needs with the lowest amount of energy. In reducing this energy, adaptation is encouraged and the associated risks of contributing to climate change are reduced. Tied to energy-efficiency are strategies promoting optimum thermal environments and minimum financial costs (Laar & Grime, 2002). Thus, contemporary tropical building designers have turned to traditional or hybrid (combinations of traditional and contemporary) materials and modifications in the building envelope to reduce dependence on climate-change-fostering artificial energy (Salmon, 1999; IPCC, 1996). This is a major pattern in adaptive housing strategies to climate change in the tropics (Ibid; Ibid).

It is here that some covert aspects of adaptation can be revealed. In architecture, there are covert themes of adaptation because buildings have been constructed in response to climate long before climate change became obvious. According to the 2007 UNFCCC report (p.10), "… *Human beings have been adapting to the variable climate around them for centuries*…" As discussed in the previous chapter, all references made to modifications in tropical housing typologies due to climate are illustrations of adaptive strategies (Butera, Adhikari & Aste, 2014; Salmon, 1999; Lawal & Ojo, 2011; UNFCCC, 2007; IPCC, 1996; Tessema, Taipale & Bethge, 2009; UNEP, 2011; Shaw, Colley & Connell, 2007). Climate adaptation in contemporary housing in the tropics may be said to be planned, as it is a conscious and well-informed effort towards adapting to the climate. However, it appears that the incorporation of mechanical thermal controls in contemporary housing is an inefficient planned adaptive feature, as it aggravates climate change. Furthermore, the way the traditional dwellings have evolved in terms of space morphology, form and construction technology demonstrates efficient autonomous adaptation (Shaw, Colley & Connell, 2007). This evolution has not only maintained cultural values but also indicated responses to climate changes which do not aggravate climate change. Therefore, contemporary tropical housing must undergo planned adaptation in response to climate change. It may be said that Short's (2017) recommendation on climate adaptation of contemporary buildings, is a form of planned adaptation. Short (2017) recommends that contemporary designers can learn from modernist public buildings of the early-mid 20th century. When examining general tropical housing evolution (see Chapter 2), modernist architecture was interpreted through the colonial buildings in tropical climes. These modernist buildings show comfortable indoor environments or naturally/passively controlled environments (based on climatic design principles), with no reliance on air conditioning (see Figure 3.9). Nevertheless, this planned adaptation can benefit from autonomous adaptation demonstrated by indigenous architecture. Consequently, a climate-responsive contemporary tropical house can be created, based on the different climate change adaption approaches; this will be discussed later.

Although it may seem that adaptive housing strategies are more popular than mitigatory options (see Figure 3.10), Urge-Vorsatz (2007) states that there is much potential for climate change mitigation in developing countries through the building sector. Hence, tropical climate change mitigation can be effected through low-carbon housing practices. 'Low-carbon' is synonymous with 'energy-efficient'; both terms indicate the utilisation of productive processes requiring the least amount of GHG generation (CCC, n.d.). It seems that mitigatory housing practices are more popular in tropical rural settings, where basic amenities associated with urban living are lacking. There is a lot of current research on the reduction of GHG emissions from biomass burning for cooking in the rural tropics, using improved cooking stoves (Urge-Vorsatz, 2007). Another common strategy is the installation of energy-efficient lighting in rural houses, using photovoltaic technology and wind-power production (UNEP, 2011). This type of mitigation is more popular in rural areas, where amenities are lacking.

The 1996 IPCC report states it is easier to implement energy-efficient technologies in residential buildings than in commercial buildings. This is one more indicator of how instrumental tropical housing can be in mitigating and adapting to climate change in local, national, and international contexts. The sudden move towards adaptation and mitigation has created a distinct type of architecture which this study has referred to as adaptive architecture. However, this adaptive architecture represents many styles arising out of responses to climate change. The most popular trend in this regard is termed 'climate-responsive architecture'. Climate-responsive architecture is also referred to by many other terms including 'climate-conscious design', 'bioclimatic design' (Lawal & Ojo, 2011, Energy Design Resources, 2002). According to Energy Design Resources (2002, p.1), "*climate-responsive design is a strategy that seeks to take advantage of the positive climate attributes of a particular location, while minimizing the effects of attributes that may impair comfort or increase energy requirements*…" The report also states tenets of climate-responsive design which include:

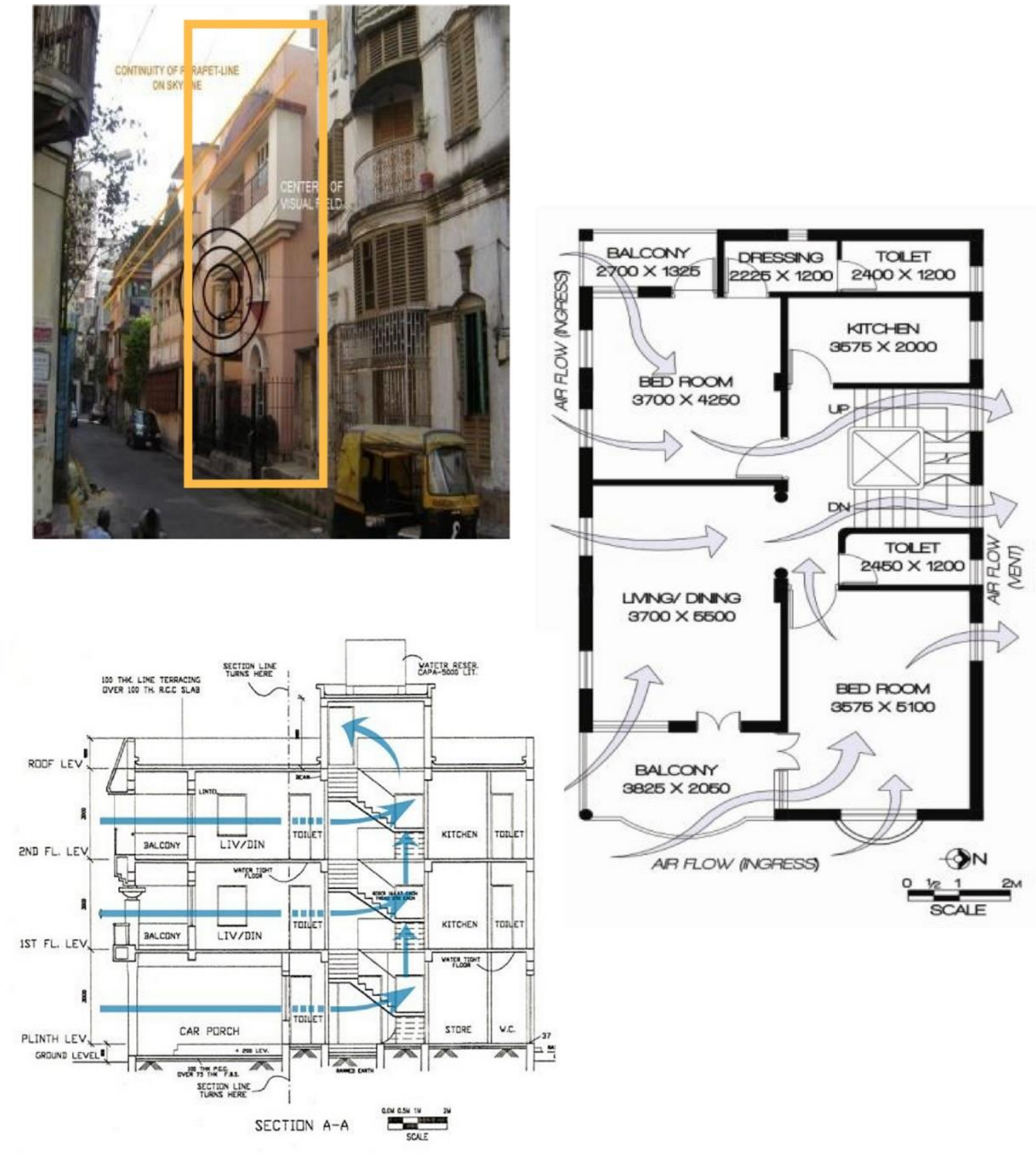


Figure 3.9 An Indian contemporary house designed in the colonial modernist style, functioning without air conditioning and demonstrating passive ventilation and cooling principles; source: Bose (2012, p.64).

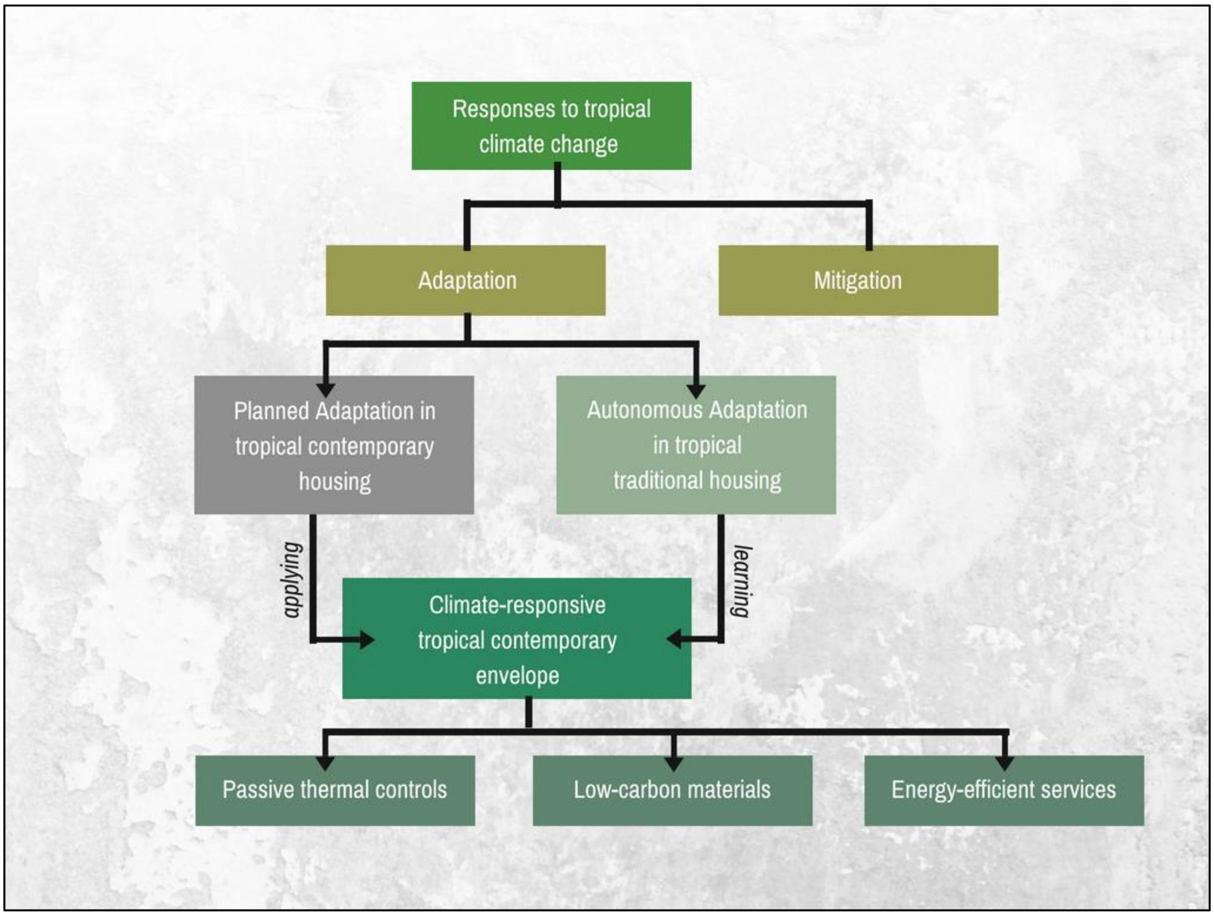


Figure 3.10 Proposing climate-responsive contemporary housing in the tropics through planned-autonomous adaptation approach; source: author's study.

1. *Understand climate zones and microclimates,*
2. *Understand the basic physiology of human thermal comfort,*
3. *Control the sun to reduce loads and enhance visual comfort,*
4. *Use thermal mass to improve comfort and efficiency,*
5. *Select space-conditioning strategies that are climate responsive.*(Ibid)

Lawal & Ojo (2011) mention some standard parameters under which building designers ensure the climate-responsiveness of buildings. These parameters include: site of the building, shape and size for the building, orientation of the building, ventilation and building fabric (walls, window sizes, roofs and floors). Additionally, Lawal & Ojo (2011) claim that these criteria can help designers in moderating indoor climate in relation to the external climate. In this moderation, climate-responsive design charges designers to make their choices based on the mutual benefit of both the indoor and outdoor climates. As seen in previous discussions, the selection of low-carbon fabric materials which contribute to optimal indoor thermal environment is high-quality climate-responsive design. Thus, the concept of climate-responsive design pervades the concept of housing in the hot-humid regions and it is indoor thermal comfort and climate-change adaptation that binds both concepts in a realistic contemporary tropical society (Butera, Adhikari & Aste, 2014).

Future tropical climates are expected to feature higher temperatures. It is here that the formerly investigated theory of acclimatisation arises. Acclimatisation insinuates that human beings can physiologically adapt to their thermal environments and therefore, changes in climate. It follows that people living in the Tropics are likely to get used to higher future temperature levels. Thus, the logic is comfort zones which govern thermal comfort in present climates are expected to become unsuitable in the future (CIBSE, 2014). This is because they will become too cool for people who have already become physiologically accustomed to the increased heat. However, these assumptions are based on cautiously-made, assumption-based and uncertain predictions that have not yet materialised (Şekercioğlu, Primack, & Wormworth, 2012; Corlett, 2014). Moreover, it can be said that these predictions are proving useful in creating awareness on cultivating and implementing appropriate responses to climate change (Nigeria. Federal Ministry of Environment, 2003).

It has been accepted that it is better to work towards these projected scenarios despite the uncertainty, to avoid regrets (Ibid). The ASHRAE 55 thermal comfort standard, which this study has chosen for its purposes, is suitable when assessing present hot-humid climates, because it accounts for acclimatisation to the high summer temperatures (Laar & Grimme, 2002). However, the question remains as to whether this standard is appropriate for future tropical climates where predicted temperatures are higher. Provision of relevant answers might entail another focused study. However, for this study, some hypothetical and logical deductions can be made based on previous analyses of the ASHRAE 55 standard and Lomas & Giridharan's 2012 study on climate-change resilience of free-running buildings. Lomas & Giridharan related an adaptive standard to ASHRAE 55's adaptive elements and compared the former with a static standard, in the assessment of indoor temperatures of free-running buildings in predicted contexts. They found that their adaptive standard was more suited to assessing free-running buildings in predicted scenarios than their static standard. Hence, it may be said that standards based on the adaptive principle have a higher suitability than static standards, to assessment of thermal comfort in future climate scenarios, and ASHRAE 55 is one such adaptive standard (Ibid; CIBSE, 2014; ASHRAE, 2010; ASHRAE, 2013).

As basic threads of tropical housing and climate change have been analysed, this study has attempted to establish thermal comfort as the link between both theories. Therefore, in the following sections, this study investigates the expression of these threads in its geographical context: south-west Nigeria.

3.4 A Developing Dynamic - South-western Nigeria and Climate Change

The 2016 CIA World Factbook report on Nigeria provides introductory information on all parts of the country, including the south-west. Nigeria is a west African country, on the boundary of the Gulf of Guinea, in between Benin and Cameroon. The country is referred as the most populous in Africa and its size is marginally more than the size of California. The country is rich in natural gas, petroleum, tin, iron ore, arable land, lead, niobium, zinc, limestone, and coal. There are two major rivers: the Niger and Benue. Its climate is generally tropical with slight variations depending on geographical zone: equatorial in the south and centre, arid in the north. It is interesting to note that the major environment issues the country faces include rapid urbanisation and deforestation, urban air and water pollution, desertification, and loss of arable land. Furthermore, natural hazards include periodic droughts and flooding. These are tied to climate change and, hence, Nigeria is a party to the Climate Change-Kyoto Protocol. Nigeria has six geo-political zones: north-east, north-west, north-central, south-east, south-west and south-south (Okunlola & Folorunso, 2015). The southern zones are coastal and have demonstrated effects of climate change impacts, rising sea levels and flooding being major effects (Nigeria. Federal Ministry of Environment, 2010). With this background information on the entire country, this study enquires into south west Nigeria.

South-west Nigeria consists of six major states: Oyo, Ogun, Lagos, Osun, Ekiti and Ondo (Faleyimu, Agbeja & Akinyemi, 2013; Idowu, 2015) (see Figure 3.11). However, the region is regarded as larger when part of Kogi and western Bayelsa, Kwara, Ekiti and Delta states are included (Omogbai, 2010). According to Ibrahim, Maruf & Alaga (2016, pp.227-228) and Omogbai (2010), the south-west Nigerian region "…*lies between latitude 5°49´ and 9°12´N of the equator and longitude 3°15´and 6°3´E of the Greenwich Meridian*…", with a total land area of 191 843 square kilometres. The region is bounded in the north by the Sahel, in the south and west by the Atlantic Ocean, making it a coastal area. The AOAV's 2013 online article provides more basic information on the region. The region's population is approximately 32.5 million people, and the Yoruba tribe (see Chapter 1), which account for 21% of Nigeria's population, are the dominant ethnic group. Economically, the region does well in relation to other Nigerian geopolitical zones. According to Bloch, Makarem, Yunusa, Papachristodoulou, & Crighton (2015), the region has the highest concentration of economic activity in Nigeria. Although the region is home to two of the country's largest and most commercial cities, Lagos and Ibadan, poverty still abounds, especially in these cities. In Lagos, almost two-fifths of the people live in overcrowded housing withinadequate sanitation. Ibadan has been chosen as the reference south-western Nigerian city for the geographical setting of the simulations that will provide the primary data for this study.

South-west Nigeria is a low-lying coastal region, also referred to as the forest zone. According to

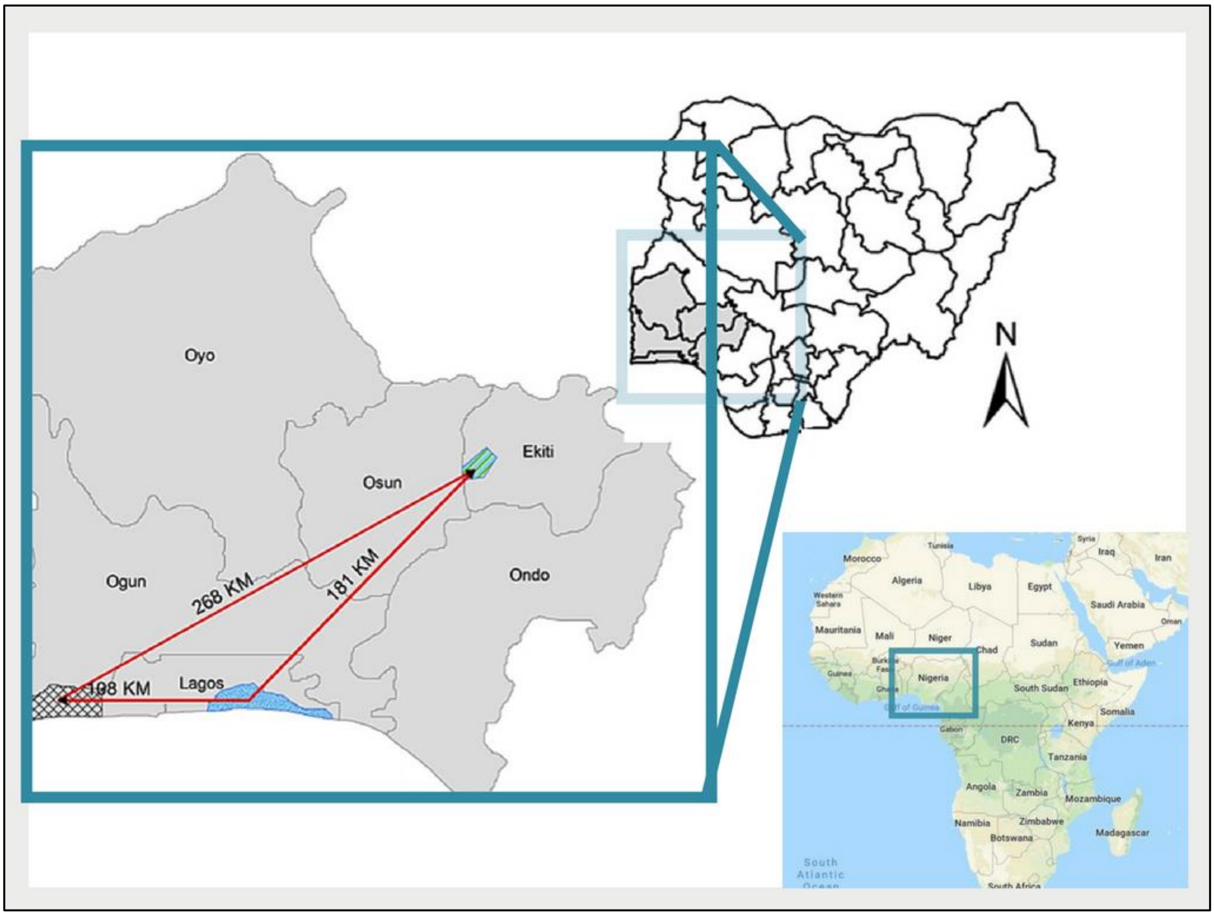


Figure 3.11 South-west Nigeria and its sub-regions; source: based on Oyebola et al (2014) and Google Maps (2018).

Omogbai's 2013 study, the region's climate is affected greatly by three major winds: the maritime tropical (mT), continental tropical (cT) and the equatorial easterlies (eE) winds. Climatic seasons are more defined in the inland parts of the region than on the coastal belts. The mT wind comes from the southern high-pressure belt just off the Namibian coast; it picks up moisture from the Atlantic Ocean in its trajectory and moves over the Equator into south-west Nigeria. This wind is also known as the south-west trade/monsoon wind and it responsible for the cool rainy season which runs from April to October (Nigeria. Ministry of Environment, 2003; Faleyimu, Agbeja & Akinyemi, 2013). Average temperatures range from 23 °C to 30 °C, making it a cooler period during the year. Even more, the lowest maximum temperatures are recorded during the rainy season, in the month of August, due to thick cloud cover (Ibid). The rains are particularly heavy, with June being the month with the highest amount of rainfall (Omogbai, 2013).

Figures 3.12, 3.13 and 3.14 respectively show the region's maximum temperature distribution, minimum temperature distribution and precipitation levels annually. Humidity levels are also very extreme due to the moisture-laden mT wind, usually 85% and above (Ibid). However, there is a short dry season known as the "August Break/Spell", lasting between 3-4 weeks (Oyewole, Thompson, Akinpelu & Jegede, 2014). After the "August Break", the rainy season resumes but rains are not as heavy as they were prior to the

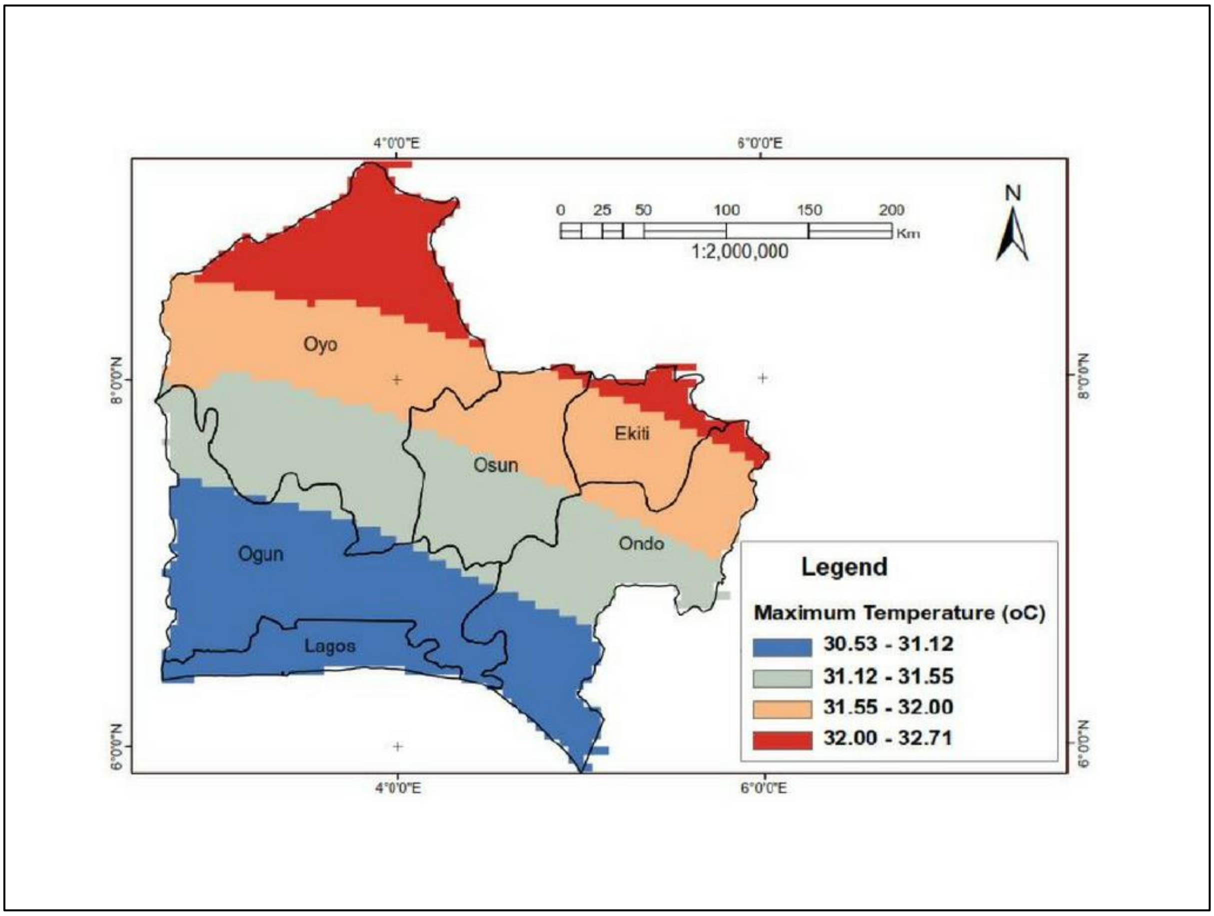


Figure 3.12 South-west Nigeria maximum annual temperatures; source: Ibrahim, Maruf & Alaga (2016, p.230).

"August break". These two periods of extreme rainfall create the characteristic double maxima event of south-west Nigerian rainy season (Oyewole, Thompson, Akinpelu & Jegede, 2014).

On the other hand, the cT wind emanates from the high-pressure belt north of the Tropic of Cancer. It also obtains some moisture but very little, making it drier than the mT wind. Alternatively, the cT wind is referred to as the north-west trade (Harmattan) wind and it ushers in the hot dry season between November and March (Faleyimu, Agbeja & Akinyemi, 2013). Temperatures rise as high as 32 °C and above. The mean minimum (night-time) temperature ranges between 21-23 °C. The highest mean maximum (daytime) temperatures are recorded in the dry season in the months of February, March and April, as high as 38 °C, despite the sun's low angle (Nigeria. Ministry of Environment, 2003; Adunola, 2014; AIACC, 2006) (see Figure 3.11). The Harmattan wind which is from the north, is dampened on its path but still reduces the humidity levels in the south-west regions. However, the two winds (mT and cT) meet on an inclining plane known as the InterTropical Discontinuity (ITD). The eE winds are unpredictable, originating from the east and flowing higher in the atmosphere along the ITD. Line squalls or dust devils arise when the eE winds sometimes settles and intersects with the mT or cT winds.

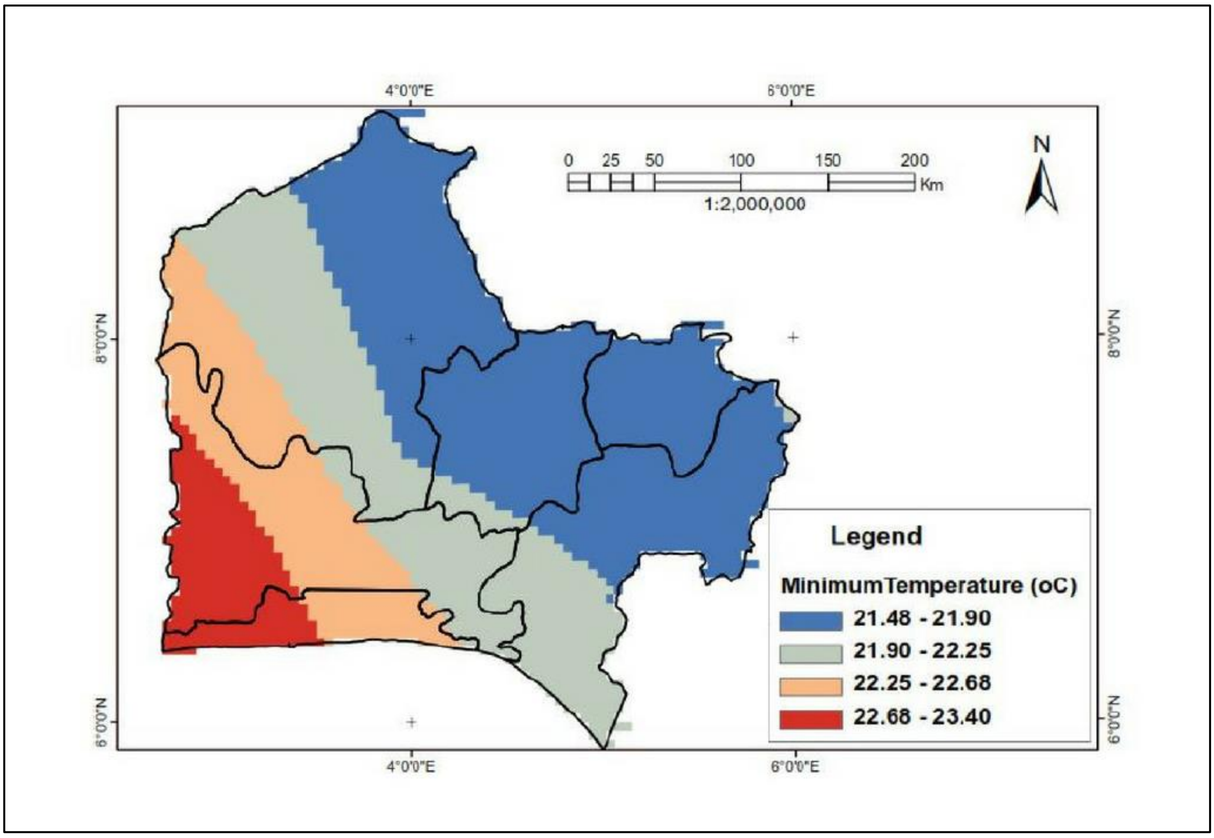


Figure 3.13 South-west Nigeria minimum annual temperatures; source: Ibrahim, Maruf & Alaga (2016, p.231).

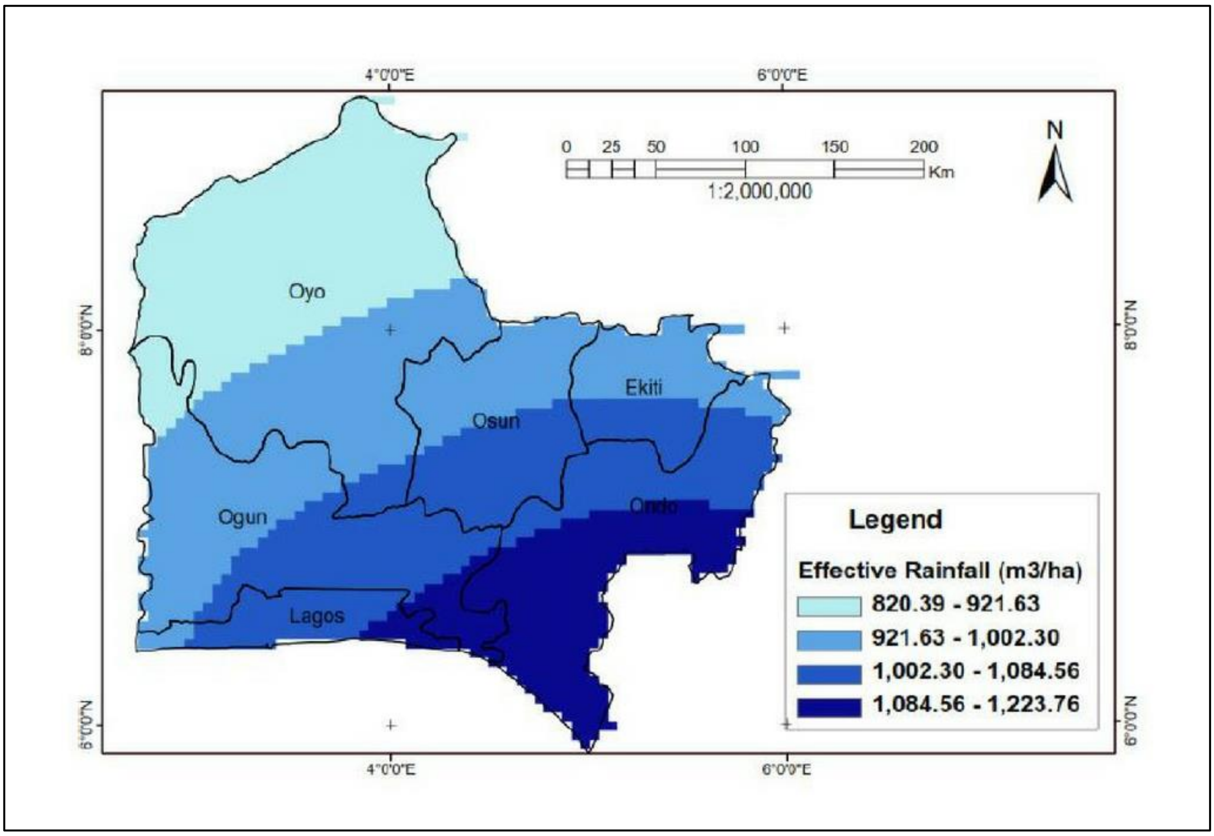


Figure 3.14 South-west Nigerian annual precipitation levels; source: Ibrahim, Maruf & Alaga (2016, p.231).

Accordingly, south-western Nigerian climate is characterised by high temperatures, humidity and rainfall, making it a tropical hot-humid region. Akande, Fabiyi & mark (2015) expatiate that the region shows a mix of warm-hot humid climates. However, recent environmental phenomena in the region have indicated that south-west Nigeria has been experiencing tropical climate change.

3.4.1 Indicators of south-west Nigerian climate change

Nigeria has only recently begun to become aware of climate change in its regions as well as getting actively involved in the global fight (Nigeria. Ministry of Environment, 2010). Therefore, most of the information available on Nigerian climate change is at a national level. The 2010 report by the Nigeria Ministry of Environment provides a good amount of this information. According to the report, Nigeria is one of the most vulnerable countries in the world; hence, its economy and other sectors can be easily affected by climate change. Still, the 2003 report by the Nigeria Federal Ministry of Environment affirms the use of climatic indicators in Nigeria, including cloud cover, precipitation, average daily, maximum and minimum temperatures, diurnal temperature ranges and vapour pressure. Conclusions based on the analyses of precipitation and rainfall have proved climate variability in all regions of the country. Therefore, these observations apply even in south-west Nigeria.

It has only been a recent development, but the increased flooding events and overflowing beaches of south-west Nigeria indicate the region's susceptibility to climate change (Mailafia, 2011; UNEP, 2011). It is projected to continue to increase in the wet season and decrease in the dry season (Nigeria, Federal Ministry of Environment, 2003). More specifically, the rainfall in the dry season is predicted to decrease by a range of 10mm – 18mm while increases in rainfall will be experienced in the rainy season by a range of 20mm – 65mm. On the other hand, Akinwolemiwa & Gwilliam (2015) report an increase in temperatures in Nigeria. Adunola (2014) specifically states that the maximum mean temperature of the south-west Nigerian city of Ibadan has risen from 30 °C in 1979 to 33.5 °C in 2009. This confirms the predicted 3-4 °C rise in temperature in the region, according to the 2003 report by the Nigeria Federal Ministry of Environment. Nights have become and are predicted to become noticeably warmer.

The above discourse shows the extent to which the south-west region has experienced climate change. However, this leads on to the question of what the causes of rainfall and temperature variability, could be.

3.4.2 Contributors to south-west Nigerian Climate Change

The 2010 report by the Nigeria Ministry of Environment states that agriculture and forestry, gas flaring, waste management, energy, transportation, land use and electricity generation are the most significant energy use processes which contribute to GHG emissions. Still more of the emissions come from energy and agriculture than from waste management and industry (Cervigni, Rogers & Dvorak, 2013; Eleri, Onuvae & Ugwu, 2013). The most well-known and fundamental cause of climate change in southern Nigeria is the gas flaring from the oil industry in the Niger Delta (UNEP, 2011). It is reported that about 24 billion cubic metres of oil are burnt annually, committing Nigeria to being one of the countries emitting the fourth highest amount of carbon dioxide globally (Ibid). This activity largely creates the thick blanket over the southern regions of the country. Of interest is the severe deforestation where over 410,000 hectares of forest are lost annually (ibid). Deforestation and agriculture are linked because the former is undertaken to make way for cultivated farmland (Eleri, Onuvae & Ugwu, 2013). This facilitates climate change as there is a huge loss of trees to absorb the carbon dioxide released by other contributors.

Cervigni, Rogers & Dvorak (2013) draw attention to the potency of solid waste dumpsites as a contributor to climate change in the region. They state that the decay of waste in landfills releases methane, a GHG 23 times stronger than carbon dioxide. Unfortunately, the south-western cities of Lagos and Ibadan have been mentioned to have several large dumpsites (Ibid). Vehicle use is another noted cause of climate change in the region. The large urban centres of south-western Nigeria feature extensive reliance on fossil-fuelled vehicles for transport of people and goods. According to Akande, Fabiyi & Mark (2015), the residential and commercial buildings sector generates the most amount GHGs among all other sectors. They also affirm that most of the GHG emissions come from the urban areas. Buildings in the urban tropics feature a dependence on electrically-powered cooling, lighting and functioning of indoor appliances. However, the infrastructure in the region and the country at large is inadequate. Consequently, Nigeria has been listed as the importer of the highest number of generating sets, making the country the largest emitter of the aerosol - black carbon (RUWES, 2015). Yet, the rural areas contribute their fair share; many rural dwellings rely on biomass burning for energy generation (Butera, Adhikari & Aste, 2014; UNEP, 2011). In this way, even the rural dimension of the energy sector contributes to the region's climate change.

The causes of south-west Nigerian climate change seem quite easy to identify (see Figure 3.15). This can be attributed to the fact that Nigeria is a developing nation and most of the contributors arise from noticeable activities pro advancement. Impacts follow the causes in obedience to the rule of cause and effect.

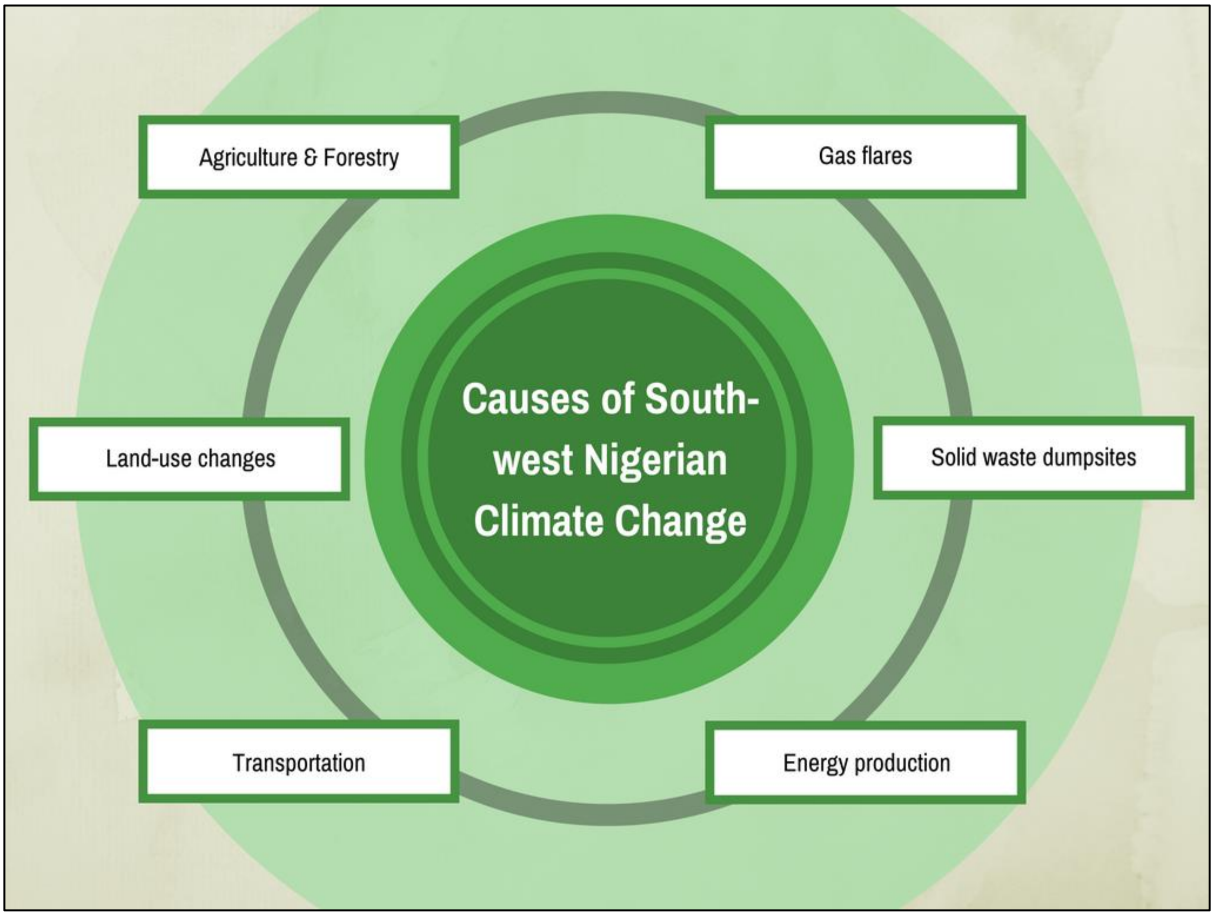


Figure 3.15 The major contributors to south-west Nigerian climate change; source: author's study.

3.4.3 Impacts of south-western Nigerian climate change

The 2003 report by the Nigerian Federal Ministry of Environment reveals the impacts of climate change in Nigeria, at national and regional levels. Most of these effects are on the different national sectors and are predicted even though they are already apparent. Hence, these impacts are obvious in the south-west region. First, reference is made to the physical and ecological systems that have begun to suffer alteration due to the flooding and subsequent erosion. The tourism sector is also affected as many of these natural systems provide the tourist attractions the country has. Examples include the south-west beaches which provide water-facilitated leisure and traditional festivals. The rise in sea levels have resulted in salt-water intrusion along the coastal regions. Subsequently, the fishery sector has begun to suffer as fish species already attuned to living in freshwater habitats cannot survive. The fishery sector is a source of food and employment in the south-west region and the negative impacts of climate change reduce the benefits it yields. The agricultural sector is also responsible for food supply and employment as well as provision of industrial raw materials and foreign exchange. Crop and livestock reared in south-west Nigeria depend on the region's substantial amounts of rainfall. Crop cycles are easily affected by changes in rainfall patterns; livestock which feed off plant matter are subsequently affected.

Water resources are vulnerable to the impacts of climate change in Nigeria. The four main sources of water in the country are rainfall, rivers and lakes, man-made reservoirs and ground water resources. In the south-west region the most commonly used are rainfall and groundwater resources (Adekalu, Osunbitan & Ojo, 2002). The 2003 report by the Nigeria Federal Ministry of Environment states that the demand for water keeps rising. Therefore, interestingly, climate change might just have a positive impact in this area as opposed to the general negativity because increase in rainfall benefits water resources. However, there is more negativity as the impacts for energy and industry are not palatable. It is reported that there is and will continue to be increasing demand on electricity due to higher needs for heating and cooling, among other activities, in buildings. Furthermore, petrochemical industrial installations concentrated on the coast are at risk. Many industries are located on the coast due to proximity to sea ports; these are at risk due to rising sea levels. This is evident in south-west Nigeria as Lagos is a coastal city with sea ports and rising sea levels have been observed (Mailafia, 2011).

Furthermore, the natural hazards characterising this region include flooding and erosion. These endanger the transport sector where land and water transport are especially prominent in the south-west region. The submergence of roads and ports, as well as storms on water bodies, are the impacts of climate change in the region. Furthermore, an increase in rainfall and rise in temperatures impacts on health of south-west Nigerians whose health status is already low, with a life expectancy of below 50 years. As discussed earlier under the general impacts of tropical climate change, the rising temperatures leave dwellers of the south-west region more susceptible to heat stroke. Higher rainfall will create more humid environments, facilitating the spread of disease-bearing vectors such as the mosquito. Flooding due to extreme amounts of rainfall also contributes to the contamination of water resources, exposing users to water-borne diseases.

3.4.4 Recipients of South-west Nigerian climate change

The recipients of climate change have been discussed earlier on; it is evident that natural and human systems suffer the impacts of climate change. The same applies in the south-west Nigerian setting. The 2003 report by the Nigeria Federal Ministry of Environment provides detailed material on the recipients of climate change in Nigeria at national and regional levels. Natural systems are recipients as indicated above by the analyses of the impacts of climate change on physical, water, tourism, and agriculture sectors. On the other hand, human systems also suffer these impacts and this study's focus is embedded therein. Human systems include health, agriculture and economy, forestry, transport, industry and energy, all apart being explicit contributors to climate change as well (Mailafia, 2011). Once again, natural systems in south-west Nigeria reveal the dual nature of human systems, being both cause and recipient. It is an interesting paradox that a causal agent of climate change would also suffer its impacts.

Here, there are many overlaps among the recipients of south-west Nigerian climate change. The GHG emissions from the energy and transport sectors pervade the atmosphere and cause global warming. Forests are depleted due to urbanisation and land use changes, removing the trees that could help absorb the major GHG-carbon dioxide from the atmosphere. then ecosystems suffer as global warming brings higher sea levels, floods and subsequent erosion. As stated earlier, the energy and transport systems suffer the impacts of the climate variability they have contributed to. The agriculture and economy sectors suffer when climate variability disturbs crop and livestock lifecycles. Environmental hazards disrupt natural features which could yield revenue as tourist attractions, reducing economic potential.

It can be said that the health sector is a prominent sector when analysing recipients of south-west Nigerian climate change. Natural hazards and a rise in temperatures endanger the lives of indigenes as earlier discussed. It seems that the health sector suffers most from climate change caused by other sectors, such as energy, industry, economy and transport (Akinwolemiwa & Gwilliam, 2015). The above statement applies especially to the quality of the built environment, which is an aspect of the health sector (UNFCCC, 2007). It has been established how energy-intensive production and transport of materials and construction contributes to climate change. The resulting warmer temperatures affect the health of building users. Then building users rely on fossil-fuel powered appliances for cooling, further aggravating climate change. Therefore, in a bid to cope with the impacts of climate change, the recipient creates more climate change, presenting another example of the paradoxes of climate change.

Additionally, it has been reported that Nigeria has one of the highest urbanisation rates in the world (Nigeria. Federal Ministry of Environment, 2010). The Nigerian government has predicted that by the year 2020, 26% of Nigerians will be living in urban centres. Furthermore, the rural-urban migration rates will increase leading to heavily populated Nigerian cities. It has already been stated in the previous chapter the rural-urban migration, is fostered by rural dwellers, seeking better socio-economic opportunities in the cities. This is already the case for major south-west Nigerian cities such as Lagos and Ibadan. Consequently, the present vulnerability of south-west Nigerian cities and infrastructure will increase due to poor planning and development. At this point it is helpful to emphasise that this study's primary focus of housing is a part of the built environment. Therefore, housing has its nature as a recipient of climate change impacts, belongs primarily to the health and energy sectors while experiencing other influences from its relationship with other sectors (Akande, Fabiyi & Mark, 2015; UNFCCC, 2007; Nigeria. Federal Ministry of Environment, 2010).

The impacts and recipients of south-west Nigerian climate change indicate a slowly but surely festering problem which requires more attention in the concerned context. The afore-mentioned paradoxes indicate that climate change in south-west Nigeria requires responses in an insightful manner. Fortunately, some basic structure towards appropriate responses to south-west climate change, exists.

3.4.5 Responses to Climate Change in South-west Nigeria: Mitigation and Adaptation

As the issue of climate change has only recently started being addressed in Nigeria, most of the country's mitigation and adaptation concepts are still at proposal stage. Most of the climate change adaptation and mitigation in the country is being cultivated as policy material. Therefore, processes for implementing mitigation and adaptation in human development are generally embryonic; this weakness has been attributed to the government's inefficiencies (Akinwolemiwa & Gwilliam, 2015). However, the establishment of bodies charged with the responsibility of managing climate change in the country shows some promise. The major national player in Nigerian climate change management is the Special Climate Change Unit (SCCU) of the Federal Ministry of Environment, which is the "*nationally designated authority for climate change in Nigeria*…" (Nigeria. Federal Ministry of Environment, 2010, p.13). The SCCU has a major responsibility to national and regional adaptation, currently partnering with international bodies such as the Heinrich Boell Foundation (HBF) and the United Nations Development Program (UNDP). Other national climate change set-ups include the Nigerian Environmental Study Action Team (NEST) and Nigerian Climate Action Network (NigerianCAN) (ibid).

On the international front, Nigeria is a signatory to the UNFCCC as one of the Non-Annex I parties. Hence, it has agreed to produce a National Adaptation Programme of Action, carry out vulnerability and adaptation assessments among others. It may seem that there is ample ground for adaptive strategies in Nigeria, at national and regional levels. Still, such policies drawn for mitigation and adaptation appear very broad, lacking enough conscientious focus to create concrete responses to climate change in the country (Akande, Fabiyi & Mark, 2015). Nevertheless, due to the efforts already made by the Government, Nigerian climate change mitigation options are quite varied. The 2010 report by the Nigeria Federal Ministry of Environment provides detailed information on these options. Policies have been made towards the conservation of ecosystems. The policies stipulate adaptive actions including proposing national parks to preserve wildlife and plants in danger of extinction due to climate-change-induced disturbances and loss of natural ecosystems. In the agriculture and forestry sector, the National Forest Policy facilitates forestry development and afforestation programmes to replace forests lost to land use changes. The policy on national erosion and flood control is geared towards the management of flooding and erosion. This shows a national and regional awareness about the impacts that climate-related dangers can have on the environment and subsequently, the people.

However, it seems that the energy sector is the most promising for mitigation. As earlier expressed, the energy sector possesses the building aspect, which has been referred to as having the most potential to reduce GHG emissions relative to other sectors (UNEP, 2009). Akande, Fabiyi & Mark (2015) echo what the 2010 report by the Nigerian Ministry of Environment in declaring the following as mitigatory options for the energy sector. The introduction of compact fluorescent light (CFL) bulbs and improved kerosene stoves is being encouraged. This strategy manifests itself as a mitigatory housing strategy as well. Another mitigatory housing strategy is the launch of enhanced electrical appliances and woodstoves. Additionally, the replacement of fuel-oil with natural gas fuel in the cement industry is being encouraged. It is interesting to note that south-west Nigeria has the highest adaptive capacity of all the country's regions despite being the least vulnerable to climate change impacts (Nigeria. Ministry of Environment, 2010). The low vulnerability and high adaptive capacity of the region has been attributed to the region's general high rainfall and superior socio-economic development respectively.

At this point, future climate change scenarios are relevant. GCMs were earlier mentioned as tools of present and future climate analysis in tropical contexts. The GCMs applicable to Nigeria are employed by the IPCC in investigating climate change in the region. The Hadley M2 General Circulation Model and the UK Meteorological Office Transient Model (UKH 1) seem to be the most popular GCMs used in Nigerian climate analyses (AIACC, 2006; Zakari, 2013). Although detailed and robust scenario analyses have not been established, the IPCC has been able to draw some future climate scenarios for Nigeria (Ibid). Basic projections about the south-west Nigerian climate state that the rainy season will become wetter and the dry season, drier; mean minimum and maximum temperatures will increase (AIACC, 2006; Akande, Fabiyi & Mark, 2015). However, the traditional patterns encompassing the duration of the rainy and dry seasons, hottest and coolest months will remain (AIACC, 2006). However, it seems that projected climate variability is uncertain in this context due to the instability in carbon dioxide (CO_2) concentrations across climate change scenarios (Ibid). Still, the one consistent trend across the scenarios, is a rise in temperature, despite CO_2 concentration variability.

Additionally, the uncertainties of the climate projections feature in SRES scenarios which were developed by the IPCC to determine future climate patterns in Nigeria (Ibid; Onyenechere, 2010; IPCC, 2000). Four scenarios SRES A1, A2, B1 and B2 have been developed (Onyenechere, 2010) (see Table 3.1). Two

SRES scenarios: A2 and B1 predict increases in rainfall between 2000 and 2100. However, SRES A2 predicts much higher and faster rises in rainfall than SRES B1. However, under both scenarios, areas of low rainfall are projected to have less rainfall while areas of high rainfall are set to experience higher rainfall. This implies that rainfall will increase in south-west Nigeria and consequently, rise in levels of water bodies and flooding event are expected. Still based on most research into Nigeria climate change scenarios, it appears the SRES B1 has the lowest amount of carbon emissions and researchers propose that Nigeria works toward a B1 future (Nigeria. Ministry of Environment, 2003; AIACC, 2006; Onyenechere, 2010). Thus, this study uses climate predictions set in the SRES B1 scenario. These projections insinuate that vulnerabilities will continue to increase unless appropriate action is taken. For this study, projections till 2050 are emphasised, but the general climate changes mentioned above, are expected to continue till the end of the 21st century (AIACC, 2006) (see Table 3.2). Some predictions based on the GCMs and scenarios from a 1990 base level, are listed in Table 3.2.

Accordingly, the nature of adaptation and mitigation at national and regional levels in Nigeria, shows laudable development of good and applicable policies but very weak execution of these policies (Nigeria. Federal Ministry of Environment, 2010; Akinwolemiwa & Gwilliam, 2015). The limitations of adaptation and mitigation implementation in the country have been traced to

- *Paucity of data and information;*
- *Limited coordination among responsible institutions;*
- *Sectoral planning and project implementation;*
- *Limited commitment of national financial resources to climate change issues;*
- *Limited private sector participation and, therefore, investment into climate change opportunities;*

(Nigeria. Federal Ministry of Environment, 2010, p.39).

Hence, authors have stated that more effort must be made towards planned rather than reactive adaptation, research, and infrastructural development (Akinwolemiwa & Gwilliam, 2015; Akande, Fabiyi & Mark, 2015). This is the adaptive strategy of capacity building (UNFCCC, 2007). Interestingly, some indication of research potential exists as some educational institutions have established climate-change research units as part of their provisions (Nigeria. Federal Ministry of Environment, 2010). Some of these units include the Academic Centre for Climate Change and Fresh Water Resources, Federal University of Technology, Minna, Niger State (northern Nigeria); Centre for Energy, Research and Development, Obafemi Awolowo University, Ile-Ife, Osun State (south- west Nigeria). These agencies are charged with the functions of climatic data collation and dissemination, training of scientists, engineers and technologists as well as promoting public awareness of climate change and the effects adaptation and mitigation strategies (Nigeria. Federal Ministry of Environment, 2003).

So far, the larger concept of south-west Nigerian climate change has been expressed. Once again, the study returns to the issue of housing, but this time in a more specific context of south-west Nigeria.

Table 3.1 The SRES future scenarios and CO_2 concentration that could occur in Nigeria's climate.

Scenarios	Storyline	CO_2 concentration by 2100
SRES A1	- A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter. - The rapid introduction of new and more efficient technologies. - Convergence among regions, capacity building and increased cultural and social interactions. - A substantial reduction in regional differences in per capita income. - Scenario develops three alternative directions of technological change in the energy system which are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).	675ppm
SRES A2	- A heterogenous world with the underlying theme of self-reliance and preservation of local identities. - Fertility patterns across regions converge very slowly resulting in continuously increasing global population. - Economic development is primarily regionally oriented. - Per capita economic growth and technological change are more fragmented and slower than in other storylines.	830ppm
SRES B1	- A convergent world with the same global population that peaks in mid-century and declines thereafter, but with rapid changes in economic structures toward a service and information economy. - Reductions in material intensity and the introduction of clean and resource-efficient technologies. -Emphasis on global solutions to economic and environmental sustainability, including improved equity, but without climate initiatives.	550ppm
SRES B2	- A world in which the emphasis is on local solutions to economic, social and environmental sustainability. - Increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. - Directed towards environmental protection and social equity at local and regional levels.	600ppm

Source: Onyenechere (2010); IPCC (2000)

Table 3.2 General Predictions for Nigeria's Future Climate Scenarios.

	2020	2030	2050
High estimate projections	Sea level might have risen by 0.3m from 1990 levels.	Energy spent in residential sector: cooking, lighting and non-substitutable electricity might have increased by almost 200% from 1995 levels. 1% increase in CO_2 emissions per annum is projected.	A rise in temperature of 5.0°C might be evident. Sea levels might have risen by 1m from 1990 levels.
	1% increase in CO_2 emissions per annum is projected.		1% increase in CO_2 emissions per annum is projected.
Low estimate projections	Sea level might have risen by 0.1m.		A rise in temperature of 3.2°C might be evident. Sea level might have risen by 0.2m.
	A rise in temperature of 0.4 °C – 1 °C might have occurred. A general rise in vapour pressure and relative humidity is expected. Projected 0.5% increase in CO_2 emissions per annum.		
	There might be a 2.8% decrease in rainfall.		There might be a 10.9% decrease in rainfall.

Source: AIACC (2006); Akande, Fabiyi & Mark (2015); Nigeria. Federal Ministry of Environment (2003)

3.5 Housing and climate change in south-west Nigeria

According to Akande, Fabiyi & Mark (2015), the domestic sector was responsible for more than half (55% - 61%) of Nigeria's energy consumption between 1996 and 2005. Additionally, their study states that the most significant use of energy in Nigerian housing is devoted to space cooling, lighting and other activities such as cooking and household appliances. 'Space cooling' is especially associated with the indoor climate, thermal comfort, and the external climate. Many studies have revealed the need for space cooling in the south-west region (Akande & Adebamowo, 2010; Olaniyan, Ayinla & Odetoye, 2013; Adunola, 2014). Olaniyan, Ayinla & Odetoye (2013) emphasise that building occupants are subject to thermal discomfort due to high temperatures, for most of the year in south-west Nigeria. The common solution has always been reliance on mechanical cooling, which is dependent on electrical energy in both urban and rural settings (Akande, Fabiyi & Mark, 2015). Additionally, most of the buildings that rely on mechanical cooling, are contemporary (Akande & Adebamowo, 2010; Olaniyan, Ayinla & Odetoye, 2013; Adunola, 2014). Earlier on it was stated that temperatures are rising in the region (Adunola, 2014). Therefore, it is no surprise that projections indicate more energy consumption, especially with the increasing rates of urbanisation. Subsequently, more reliance on GHG emitting energy production will increase, aggravating climate change in the region; all these will happen if drastic mitigation and adaptation is not enforced. Positively, there is already awareness of adaptation in the residential sector. Promoting thermal comfort and energy-efficiency have become the primary tools in enforcing climate change adaptation as well as providing optimum indoor climates (Akande, Fabiyi & Mark, 2015).

Moreover, Akande, Fabiyi & Mark (2015) encourage the design of resilient contemporary buildings which provide thermal comfort without mechanical support, in the Nigerian context. Therefore, the opportunities for adaptation through the careful selection of building construction and materials have become recognised at national and regional levels. Planned adaptation, involving extracting lessons from autonomous adaptation, has become the major theme for adaptive housing strategies in Nigeria. This may be said to involve a conscious design of contemporary houses based on climatic design principles (discussed in Chapter 2) while learning from the unconscious, spontaneous climate-responsiveness of traditional housing. Consequently, designers have embraced the concept of blending the traditional and contemporary to create climate resilient housing. Many professional practices are committed to enforcing adaptation in their designs. They create residencies where traditional construction and materials, and spatial planning are integrated with contemporary energy-efficient utility systems. However, more innovation is being sought after in research; more investigations into climate-responsiveness of contemporary south-western Nigerian housing is necessary. In the words of Akande, Fabiyi & Mark (2015, p.149), "…*For instance, local traditional materials having lower embodied energy and much smaller environmental impact when compared to other building materials (i.e. bricks, concrete and iron) are yet to be fully explored for residential building envelope in Nigeria*…"

A major benefit of exploring climate-change adaptation in contemporary south-west Nigerian housing is the potential to create comfortable indoor thermal environments devoid of artificial conditioning (Akinwolemiwa & Gwilliam, 2015). Thermal comfort connects climate change and housing in the Tropics. South-west Nigerian architectural researchers and designers have found this statement to be true in their context, especially in making contributions towards climate change adaptation in the region and country. Many studies have been undertaken on thermal comfort in south-western Nigeria with regards to adaptive techniques. Lawal and Ojo (2011) carried out a study on the relationship between building types and thermal comfort in the south-west Nigerian city of Ibadan. They found that vernacular buildings of plastered adobe mud bricks, with cement sand rendered flooring and roof covered with corrugated iron sheets displayed the most comforted indoor thermal environment amongst the four building types studied. Additionally, Adunola (2014) aimed his research at finding out the effect outdoor temperatures have on indoor temperatures in residential buildings of Ibadan. He discovered that most contemporary envelopes needed more thermal effectiveness in terms of design and building envelope specifications.

Accordingly, it seems that researchers in the concerned context have found that thermal comfort depends on the nature of the building fabric as it determines the interaction between the outdoor and indoor climates. Thus, thermal comfort is an indicator of climate-responsiveness of the building fabric. The adaptive solutions they proffer are directed towards thermal comfort and energy-efficiency in present climates. Another popular trend is the use of computer simulations to evaluate residential building performance in south-west Nigerian climate. More specifically, Olaniyan, Ayinla & Odetoye, in their 2013 study, investigated the thermal performance of the building envelope using a virtual model in a simulated current environment of Southern Nigeria. Their results revealed the parts of the building envelope that contributed to its underperformance and they suggested ways to alter these building envelope components. However, their study does not provide any hard data to prove that these suggestions advance the building envelope performance. Therefore, there appears to be a gap in knowledge where research on the dynamics of thermal comfort, the building envelope and future climates in south-west Nigeria can be investigated (see Figure 3.16). Furthermore, it is necessary to determine if improving thermal performance of the south-west Nigerian contemporary residential building envelope, can work, virtually and realistically, in present and future climates. Still, south-west Nigerian housing is so much

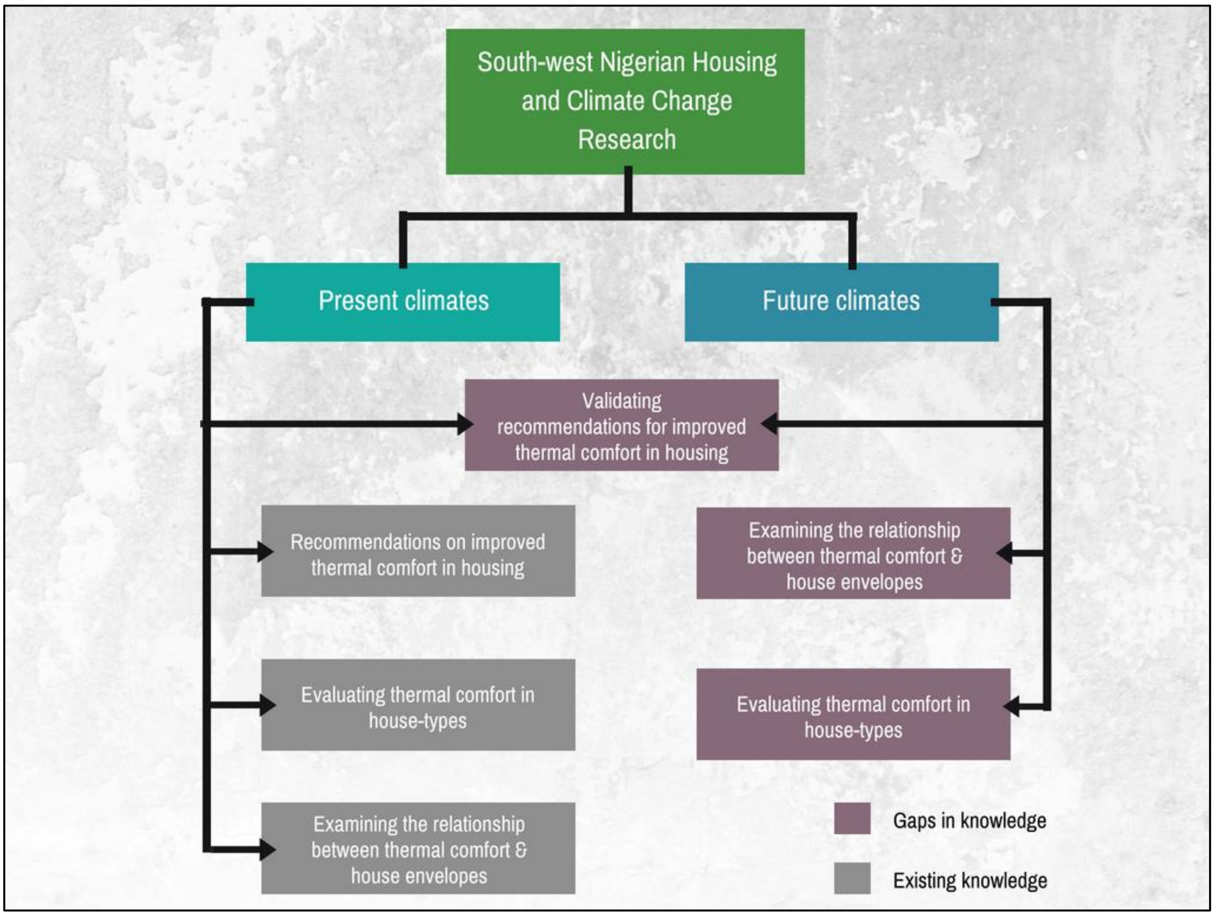


Figure 3.16 Existing knowledge and accompanying gaps in the field of south-west Nigerian housing and climate change; source: author's study.

more than its building envelope. Hence it is necessary to investigate the entire concept of south-west Nigerian housing and its evolution through time. It seems beneficial to investigate forms of climate-change adaptation in south-west Nigerian housing trends through time (Akande, Fabiyi & Mark, 2015).

3.6 Conclusion

This chapter has examined tropical climate change at large and, in the study's geographical focus of south-west Nigeria, in terms of its causes, indicators, impacts, recipients, and the adaptive and mitigatory responses to the phenomenon. It has settled that housing is a human system vulnerable to climate change but capable of great adaptive and mitigatory potential. Therefore, enquiring into the connection between climate change and housing in the tropics and south-west Nigeria, has taken the study back to thermal comfort and the building envelope once again. This chapter has shown this connection has enormous potential as a jumping-off point for climate change adaptation. Research in climate change adaptation has shown that the planned and autonomous adaptation approaches are the most efficient in developing climate-responsive architecture. Planned adaptation ensures that contemporary envelopes are intentionally created to adjust to the external climate, without aggravating climate change and create thermally comfortable interiors. The design of contemporary envelopes through the planned adaptation approach, can be augmented by learning from the autonomous climate-adaptive features of traditional envelopes as well. Thus, this chapter states that using a planned-autonomous adaptation approach, climate-responsive contemporary tropical house envelopes can be cultivated. Additionally, the chapter has mentioned that cultivating climate-responsive tropical house envelopes is possible using climatic design principles, discussed in Chapter 2. It is at this point that this study goes on to investigate the evolution of south-west Nigerian housing and determine the potential for climate-responsive south-west contemporary domestic envelopes (Nigeria. Federal Ministry of Environment, 2003; Ibid, 2010). The next chapter examines the journey of the south-west Nigerian housing and corresponding envelopes through chronological and cultural changes.

Chapter 4

South-western Nigerian domestic envelopes and climate-responsiveness – A historical and social perspective

"History cannot give us a program for the future, but it can give us a fuller understanding of ourselves, and of our common humanity, so that we can better face the future."
Robert Penn Warren, 1961

4.0 Introduction

This chapter investigates the historical and cultural evolution of south-west Nigerian housing and corresponding envelopes. Through this investigation different classes of south-west Nigerian house envelopes are identified based on socio-cultural changes through time. The climate-responsiveness and climate adaptation approaches across the different envelopes are evaluated. Therefore, the relationship between climate change and the south-west Nigerian house envelopes through climate-responsiveness and climate adaptation, is examined. Summarily, the main purpose of this chapter is to reveal what potential for climate-responsiveness and adaptation exists through contemporary south-west Nigerian housing.

4.1 Roots revisited – South-west Nigerian Housing before 1900

The Yoruba tribe have predominantly occupied the southwestern region of the country since the seventh century B.C., living in large urban communities (Osasona, 2007). Their traditional towns demonstrated planning similar to contemporary urban centres. According to Watson (1999), the Yoruba had their own cities and urban systems before the foreign influences. The typical Yoruba town had three social levels which were reflected in spatial or morphological structure. The first was the primary unit represented by the patrilineage or kin group. The patrilineage was the socio-cultural basis for the fundamental residential unit structure: the compound. The second level was the quarter which constituted a group of lineages and accompanying compounds connected by a rectangular road system. The quarter was an administrative unit overseen by a chief which was a member of the lineage (see Figure 4.3). Certain chieftaincy titles belonged to particular lineages and succession was inherited in the lineage. Denyer (1978) adds that the quarters were built along the town's minor roads. The quarters were arranged around the palace; thus the town spread out like a spiral and all its areas were largely uniform (see Figure 4.1). The head of each compound in a quarter was responsible to a chief who was responsible to the king or *oba*. The town was

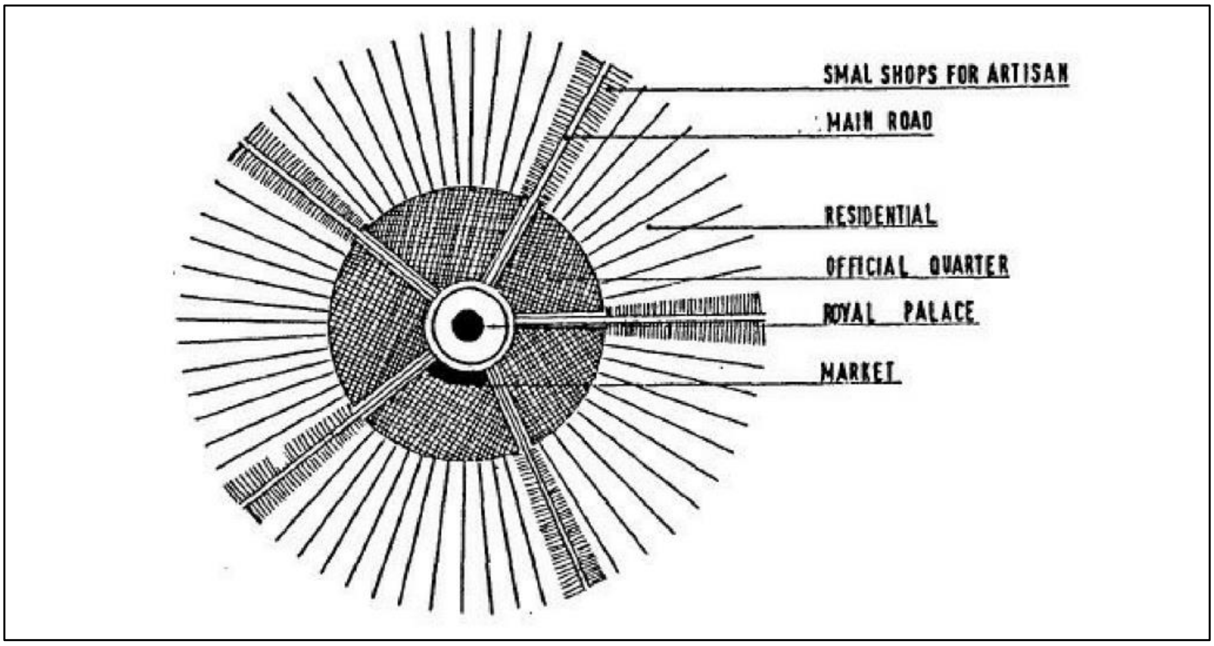


Figure 4.1 Abstract representation of the typical socio-morphological structure of a traditional Yoruba town; source: Aboutorabi (1985, p.34).

the third and final level, where all the residents, accompanying quarters and chiefs, formed a political community ruled by the *oba*. The *oba* came from the royal lineage which descended from a town founder from the first Yoruba town: Ile-Ife. The Yoruba regard Ile-Ife as the cradle of Yoruba civilisation and the origin of humankind (Ibid; Dmochowski, 1990).

Furthermore, the morphology of the typical Yoruba town featured perimeter walls built for defence (Denyer, 1978; Mabogunje, 1971) (see Figure 2). The walls were built of mud mixed with stone and water (sometimes oil). They were as high as 4.5m, about 4.5m thick at the base and got narrower towards the top. Initially, some towns were protected by up to 3 concentric walls in addition to trenches, especially where thick forest surrounded the town. The northern Yoruba town of Gboho had three walls, while Ilesha and Ife had two each. Later, during the nineteenth century wars, these walls got thinner - as thin as about 1m - to allow for gun holes when guns were introduced to the towns (Denyer, 1978). Accordingly, the hierarchical social system, socio-cultural bonds and values, as well as a traditional agrarian lifestyle, were reflected in their domestic architecture (Fry & Drew, 1964). Three types of traditional Yoruba housing may be identified based on the traditional socio-cultural and economic structure (Denyer, 1978; Dmochowski, 1990; Akinsemoyin & Vaughan-Richards, 1977). These are the king's palace, the chief's house and the civilian's house. The civilian's house illustrates the basic unit of Yoruba housing: the compound/courtyard house. According to Denyer (1978), the Yoruba traditional courtyard house is classed under the Impluvial Style of African forest regions. Other ethnicities of the African forest regions such as the *Bini* and Ekoi of southern Nigeria and the Asante of Ghana, imbibed this style. The impluvia of the African forest region has been likened to the impluvia of ancient Egyptian and Roman houses (ibid).

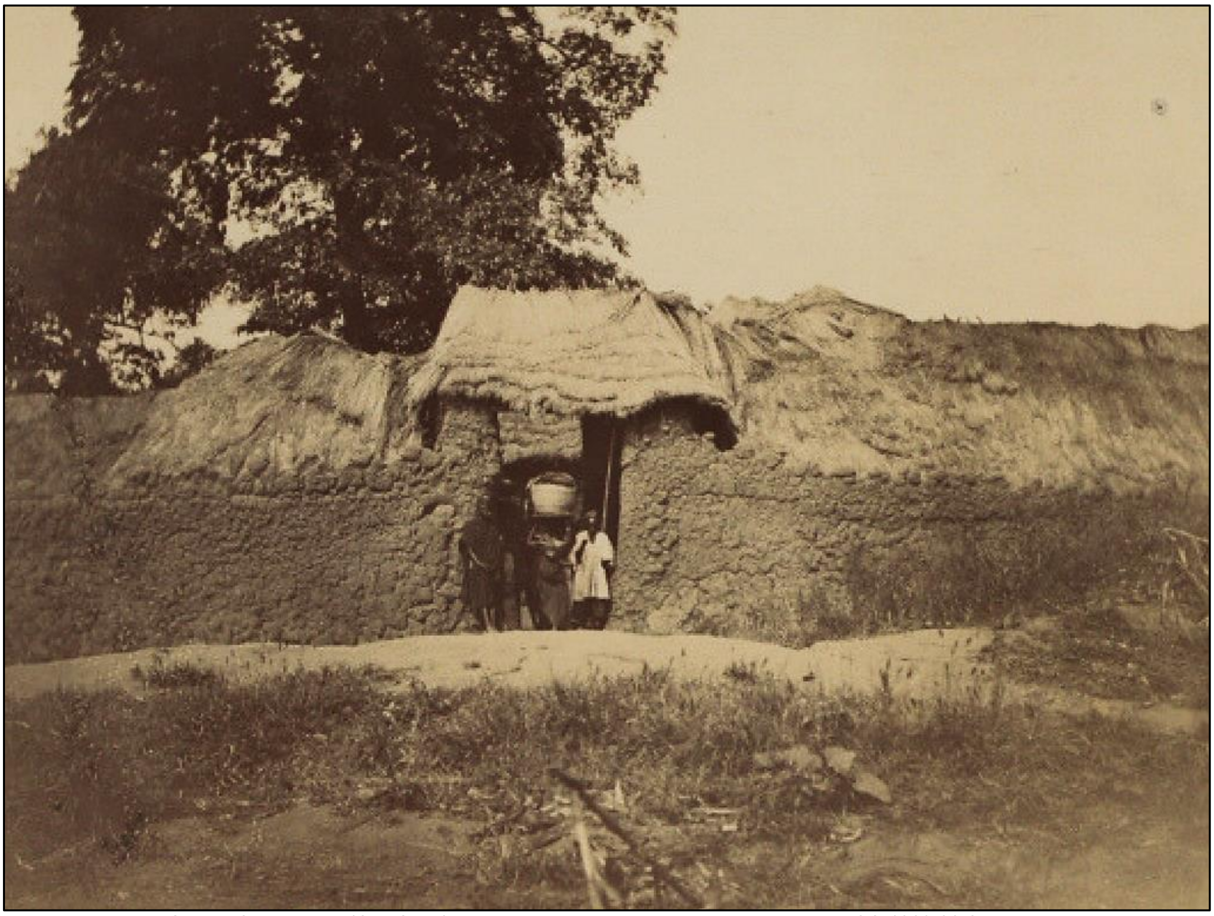


Figure 4.2 Gate in Ogbomosho (Oyo State) town wall; source: The National Archives UK, CO 1069-80-2 “Nigeria” undated.

Figure 4.3 View from Olumo Rock Abeokuta with River Ogun in distance, showing aerial view of compound houses in quarters; source: The National Archives UK, CO 1069-80-3 “Nigeria” undated.

A typical compound house was called *agbo-ile* meaning 'flock of houses'. Every person associated with a family belonged to an original *agbo-ile*; it represented the *orirun* meaning 'origin' or 'source of the ancestors'. Figure 4.4 shows the typical floor plan of the *agbo-ile*. The caretaker of the *agbo-ile* was the oldest man called the bale; the bale was the head of the family as well (Denyer, 1978). There was an anterior and a posterior entrance (Jiboye & Ogunshakin, 2010). The anterior entrance gate led into an introductory room or akodi which then led into a courtyard positioned within the separate apartment units (Dmochowski, 1990). Usually, four blocks of single apartments with one side of each block left open and facing the courtyard. Hence the compound house had a quadrangular plan and a perimeter wall about two metres high (King, 1984). The apartments belonged to members of a closely-related and paternally-related families; the single units were positioned according to seniority. The bale's apartment was positioned at the entrance of the house, next to the welcoming room or *akodi* (Denyer, 1978; Adedokun, 2014b). Usually, his apartment was the largest of the units and closest to the entrance as he was the most important family member. The bale's room was next to the *akodi* as he needed to monitor visitors for reasons of privacy and security (Adedokun, 2014b). In some cases, the bale's room was linked to a harem, garden and the other apartments (Denyer, 1978).

The single apartments or *oju'le* were small, based on a basic block of approximately 3m (*ese bata mewa*), and commonly devoid of windows; if there were any windows, they were small (Adeokun, 2013; Adedokun, 2014b). Thus, the *oju'le* were designed as they were only occupied at night, used for sleeping and the storage of personal and prized belongings. In the central, open courtyard space, activities such as cooking, laundry, storage of communal and regularly-used items and entertaining guests occurred (Osasona, 2007a) (see Figure 4.5). Festivities and family meetings were held in this vital space as well; it was the core of the home. The posterior entrance led to supplementary spaces which served as bathrooms or extra kitchens (Adedokun 2014b). Around the courtyard was a colonnaded veranda or *oode,* covered with the long overhangs of a saddle-shaped roof with a pitch of 40° - 60°, which reduced the sun's glare (Adeokun, 2014b). The columns of the veranda were often modestly decorated timber posts (Denyer, 1978). The veranda connected the courtyard with and provided access to single rooms/huts or *oju'le*. Additionally, the veranda was supported by elaborately decorated posts and covered in lean-to roofs which were 1.8m long extensions of the house's major gable roof (Dmochowski, 1990). Roof members were held together by rope fibres of *aja* to form a pyramidal, thatch-mat-covered roof where valuables and dry food were stored (Adedokun, 2014b). The ceiling was made of thick layer of mud/clay, under which unrefined palm fronds and bamboo were arranged (Akinsemoyin & Vaughan-Richards, 1977). The thick layer of mud helped to prevent fire. Okeyinka & Odetoye (2015, p.26) add that the courtyard is better described as an impluvium as the roof "*…extended into shallow, sunken cisterns*

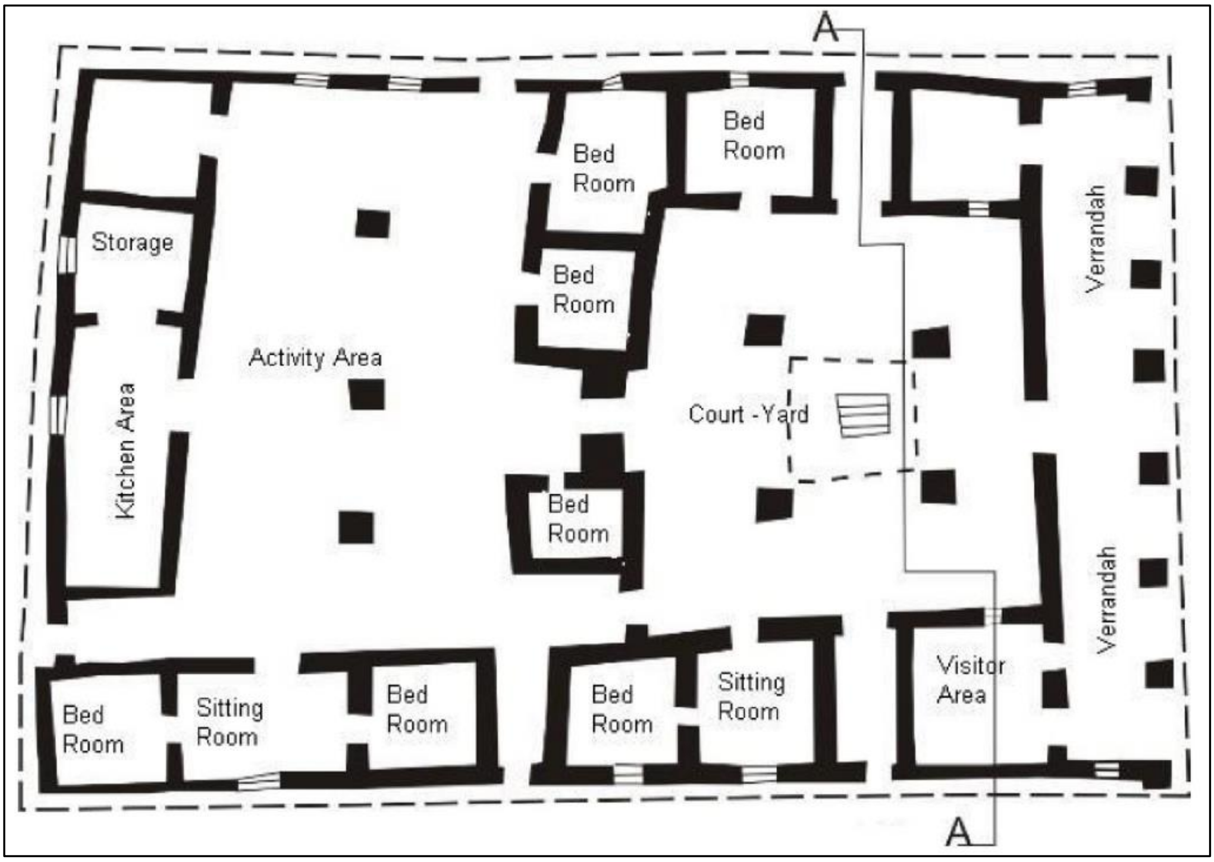


Figure 4.4 Typical layout of the Yoruba traditional courtyard/compound house; source: Jiboye & Ogunshakin (2010, p.127).

Figure 4.5 A courtyard within a traditional compound house in Ife (notice thatch gable roof and mud walls); source: Frobenius-Institut, Frankfurt am Main, FoA 04-5006, undated.

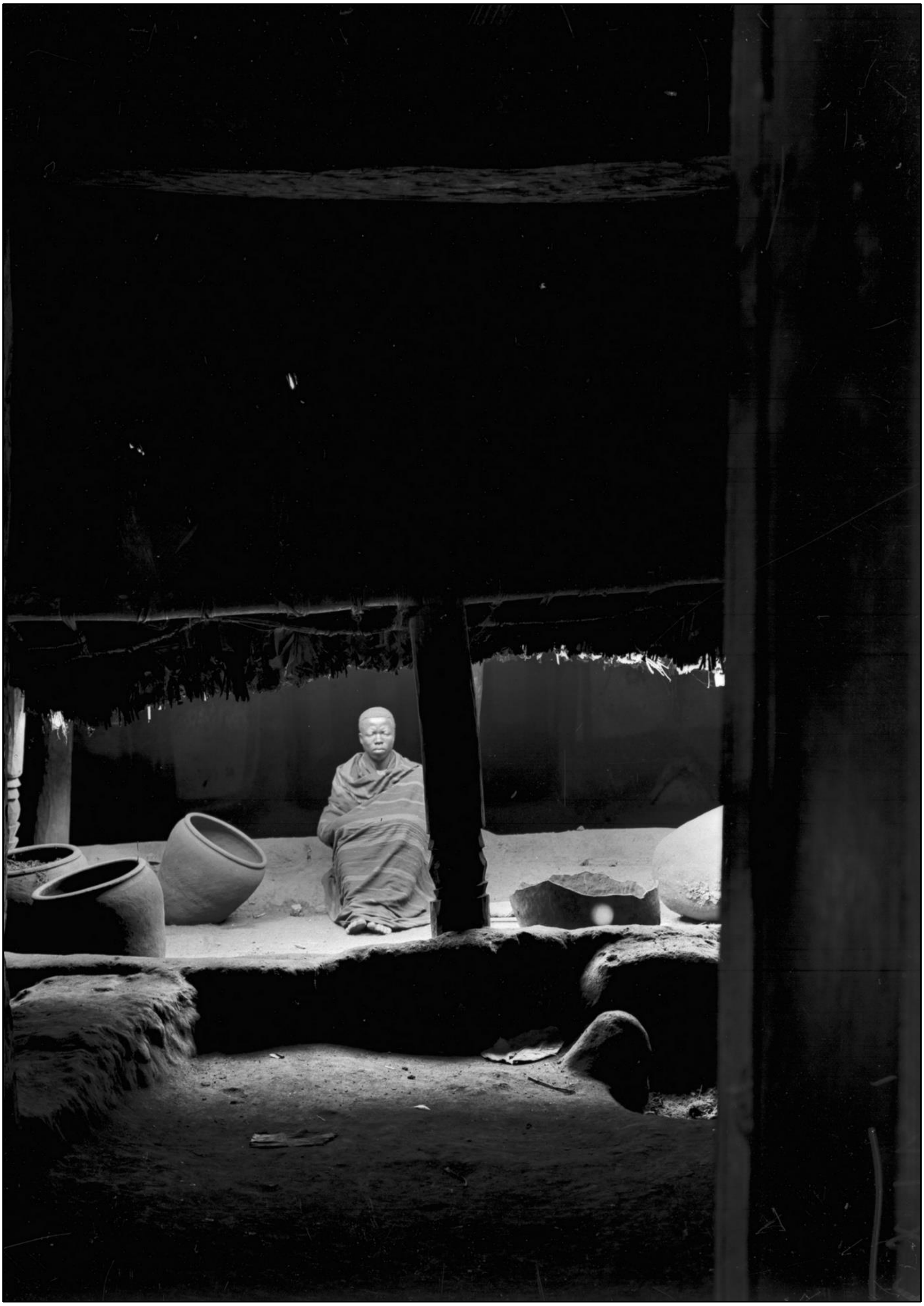


Figure 4.6 Impluvium within the traditional compound house in Ife; source: Frobenius-Institut, Frankfurt am Main, FoA 04-5033, undated.

in the centre of the courtyard space…" (see Figure 4.6). According to Denyer (1978), the impluvium aided rainwater harvesting where water was drained into pots. Rain water drained from the roofs into the impluvium. Sometimes water was collected from the lean-to roof using funnels placed in smaller impluvia. Dmochowski (1990) describes this funnel system as a compluvium. In section, the hips of the lower compluvium formed a funnel-like shape and looked like an upside-down trapezium supported by four forked one-meter high columns. The water was collected in large clay pots and waste water was drained out of the house through a duct under the floor of the veranda.

In some other Yoruba settlements such as Ile-Ife, the courtyard family house was modified, creating the *Orowa* house type (see Figure 4.7). Okeyinka & Odetoye (2010) maintain that the *Orowa* was employed by nuclear families as opposed to the courtyard house, which favoured the extended family structure. Hence the former was not as popular as the latter. Adeokun (2013) provides a rich expose on the *Orowa* type which is classed as one of the earliest survivors of the pre-colonial era. This type's lack of an impluvial courtyard differentiated it from the courtyard house. Additionally, the spaces with the *Orowa* house were interconnected one with the other but primarily through the roofed large focal hall or *orowa*. As with the compound house, there was sometimes an anteroom (*akodi*) preceding the *orowa* while a front veranda introduced the anteroom, in the *Orowa* house. The *orowa,* bedrooms and anteroom performed the same functions as those of the courtyard, bedrooms and anteroom respectively, of the courtyard family house. The *oju'le* of the *orowa* house were small with approximate dimensions of 2.8m by 3.0m, and usually did not have windows, just like those of the compound house. Furthermore, each bedroom belonged to one person except in the cases where a wife would have a cluster of rooms to herself and her children. Hence, multiple households or family clusters lived in the courtyard house. According to Adeniji & Ogundiji (2009), up to 12-15 households/family cluster could live in the traditional courtyard house as extended family members were always welcome. Furthermore, the number of people in each cluster fell between 3-10 people. As in the courtyard type, the head of the family had a room to himself and manned the *akodi*.

However, other variants of civilian Yoruba traditional housing may be identified, especially due to geographical differences among Yoruba towns. Akinsemoyin & Vaughan-Richards (1977) identify housing in pre-colonial Lagos. The poorest indigenes lived in small mud houses with an elliptical layout, made of mud walls with no windows and thatch roof (thatch from palm leaves). The house was raised on a platform to prevent flooding. Another house-type available to the poor had walls made of rows of tied bamboo tied and placed in a vertical position. The roof comprised of poles overlaid with palm leaves. A third variant of the poorer house-type was the stilted house found close to the waterfront (see Figure 4.8). Generally, this type is similar to the houses of the riverine dwellers such as the western Ijaw (Brisibe, 2016a) (see Figure 4.9). Mangrove poles were used to erect the structural framing of this house-type, including the supporting

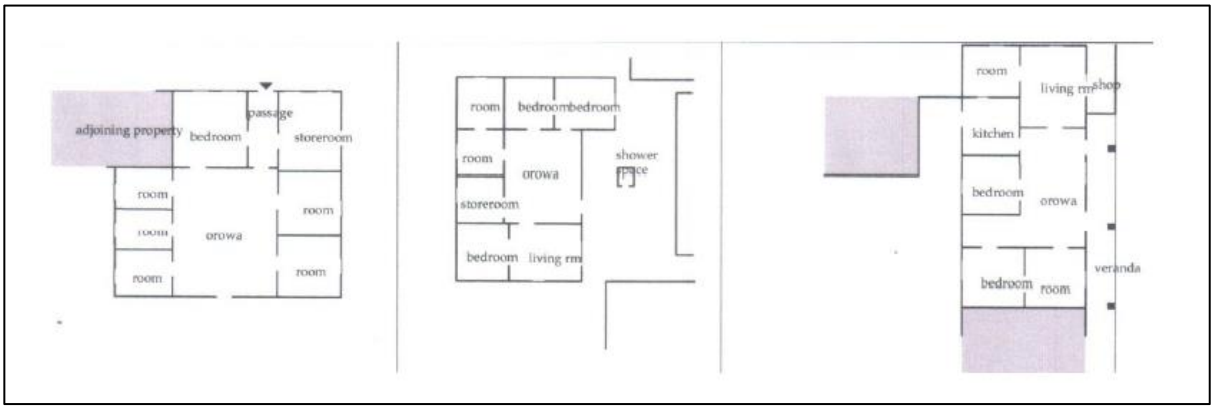


Figure 4.7 Floor plans of the Orowa variant of the traditional compound house; source: Adekoun (2013).

stilts; the roof was made of thatch. Fishing canoes were anchored to the stilts. Still, the wealthier civilians and aristocrats built compound houses with the typical Yoruba layout and construction. Another type of housing was introduced into the Yoruba settlements in Lagos by interaction with the *Bini* Kingdom of mid-west Nigeria (Ibid). When the *Bini* chiefs acquired land in Lagos from its earliest rulers, the 'white-cap' or *Idejo* chiefs of Lagos, they built well-arranged houses. These houses were constructed in the pattern of

Figure 4.8 Stilted waterfront house in Lagos (Agege), showing timber framing and thatch roofing; source: The National Archives UK, CO 1069-78-28 "Nigeria" undated.

Figure 4.9 Stilted waterfront house of the Ijaw showing similar construction to the stilted house in Agege; source: Brisibe (2016b, p.474).

the Bini noblemen's houses (see Figure 4.10). According to Osasona (2007a), the traditional *Bini* house is similar to the that of the Yoruba courtyard house in terms of layout and construction. The *Bini* house was rectangular in layout, with many quadrangular spaces around an impluvial courtyard. The single apartments and courtyard served similar purposes with those of the Yoruba courtyard house (Ibid). However, a peculiar feature of *Bini* domestic architecture was the fluted (ribbed) walls of the *Oba*'s and chiefs' palaces (Ibid, Domchowski, 1990, Denyer, 1978) (see Figure 4.10). Dmochowski (1990) explains that a metal knife bent into a hook was used to cut out the horizontal flutes in the walls. A large snail shell was used to cut out the flutes occasionally. The fluting created an appealing aesthetic quality. Therefore, courtyard houses with ribbed walls existed as a variant of the courtyard house in Yorubaland, due to *Bini* influence. Chokor (1993) adds that due to nineteenth century ethnic wars, temporary huts with thin mud walls existed in the first Ibadan settlement; they afforded the occupants a quick escape during attack, fire or natural disasters.

Nevertheless, the courtyard layout of the *agbo-ile* was the basic motif for the more complex traditional Yoruba houses: the chief's house and the king's or oba's palace (Denyer, 1978; Mabogunje, 1971; Dmochowski, 1990; Akinsemoyin & Vaughan-Richards, 1977). Both types are termed palaces or *'afin'* because they demonstrated more sophisticated design than the common houses (Dmochowski, 1990). Dmochowski (1990) elaborates that the palaces of the Yoruba kings and chiefs may be classed into three categories based on the level of their influence. The first category constitutes the pure *afins* which were home to the original rulers of Yorubaland. In this category, in descending order of rank, are the *afins* at Ife, Oyo, Ijebu-Ode and Abeokuta. Ife is first in this class because it is regarded as the original home of the Yoruba and the *Ooni* of Ife is the ceremonial head of the Yoruba. The second category constituted the *obas* who had historical connections to Ife or any of the other major towns. The third category was

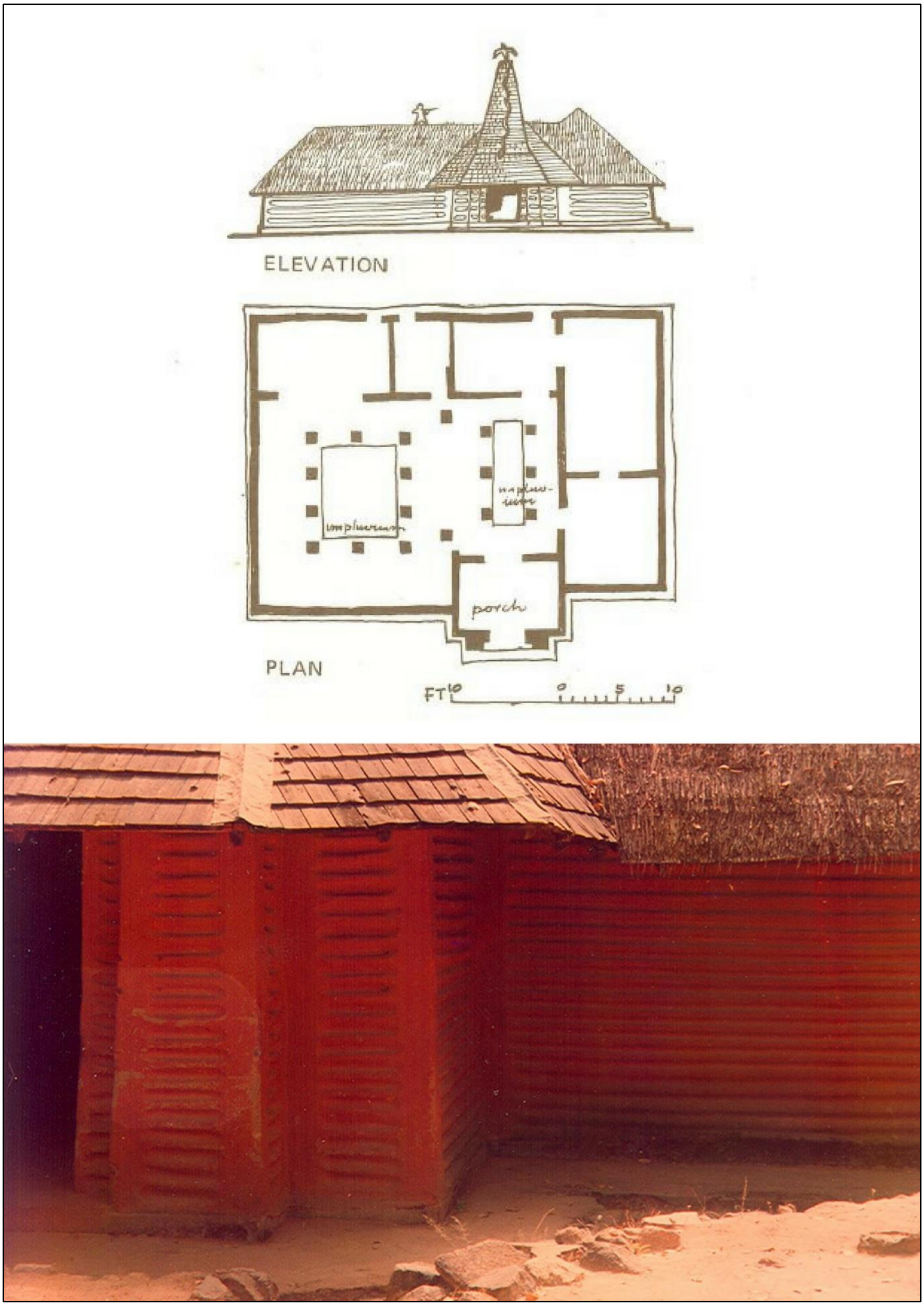


Figure 4.10 House of a Benin aristocrat which was built in precolonial Lagos – notice fluting on exterior walls; mud and thatch construction and compound layout similar to that of the *agbole*; source: top image (sketch) – Akinsemoyin & Vaugahn-Richards (1977), bottom image (photograph) – Osasona (2015, p.44).

made up of the chiefs' or *bales'* houses. The chief's house was distinguished by a high saddle pyramidal roof structure (*kobi*) adjoining the main gable roof which extended over an anterior veranda (Denyer, 1977; Mabogunje, 1971) (see Figure 4.11). According to Dmochowski (1990) and Denyer (1978), a typical layout consisted of the elaborate anterior veranda with columns which ranged from ornamental sculpted caryatids to thick mud pillars (sometimes decorated) (see Figure 4.10). Dmochowski (1990) adds that the caryatids were sculpted from special trees, in the likeness of human, animal and mythological figures. Sometimes, one caryatid was created by 1-3 figures arranged one on top of the other. Furthermore, the doors, beams, and ceiling boards were decorated with geometric shapes, human, animal and mythological symbols. The veranda led to an entrance courtyard with an impluvium and enclosed in another veranda. The impluvia of the chief's house was wider than those of the commoner's house (see Figure 4.12). The veranda led into a lounge and rows of single apartments (see Figure 4.12). Other variants of the chief's house had more than one courtyard; some had up to three. The first courtyard was a public space and provided access to the other private courtyards. The private courtyards had impluvia and colonnaded verandas as well. Additionally, decorated architraves and parapets commonly characterised the courtyards of the chief's houses. The private apartments of the chief and his family surrounded the private courtyards in a complex layout.

Figure 4.11 Traditional house of a Yoruba chief – notice pyramidal roof structures or *kobi* typical of a chief's or king's palace; source: Frobenius-Institut, Frankfurt am Main, FoA-04-5081, undated.

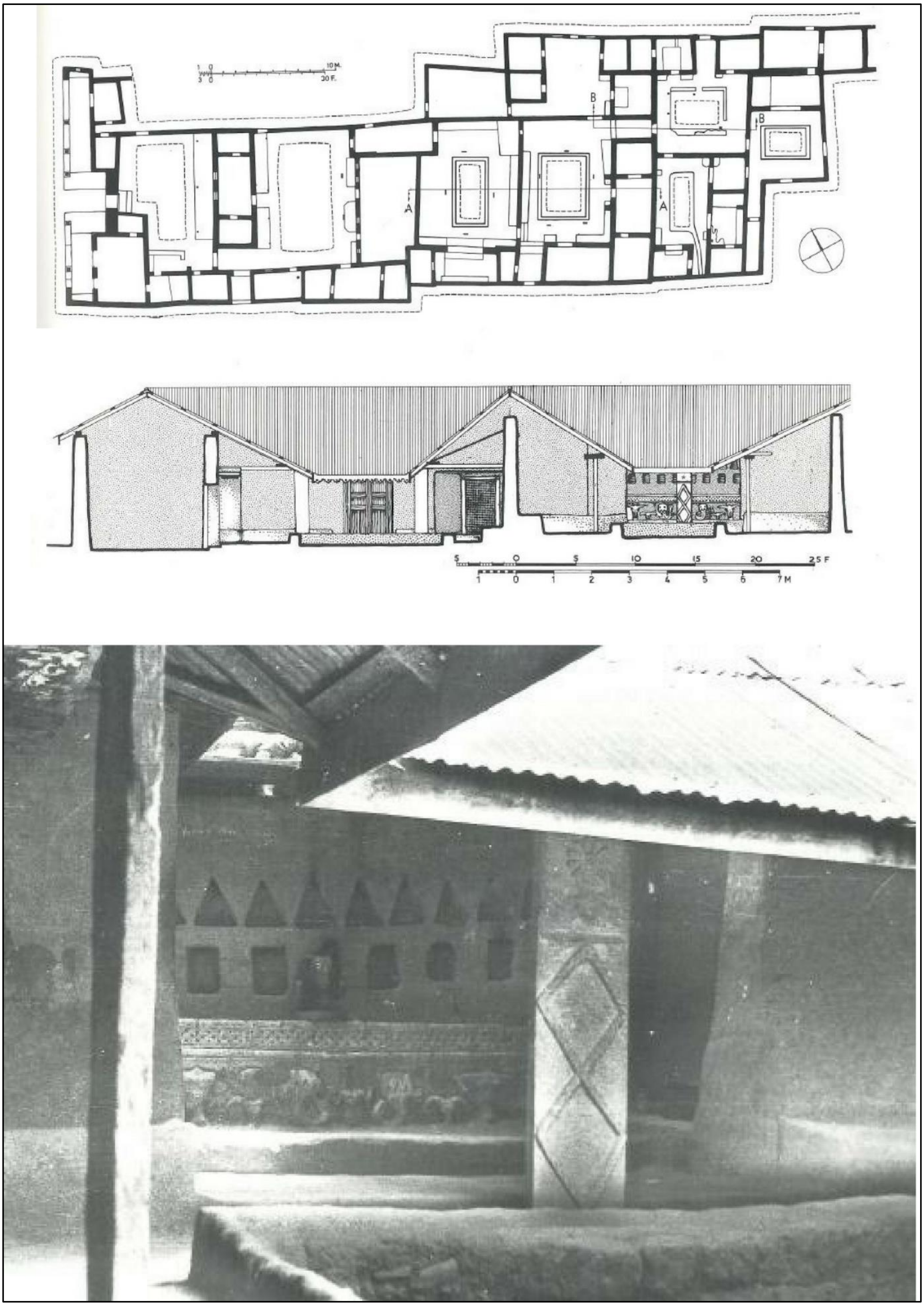


Figure 4.12 Chief's house in Owo, Ondo State – notice courtyard impluvium and ornamentation on mud columns and walls signifying the high social rank of the occupant; source: Dmochowski (1990, p.2.58-2.59).

The Yoruba traditional palaces form the most intricate house-types due to their socio-cultural importance. However, the convoluted layout of the typical palace was based on the primary courtyard house plan. The palace was made up of many courtyard units which had highly decorated interiors and exteriors (Denyer, 1978; Dmochowski, 1990) (see Figure 4.13). The courtyard columns and caryatids supported the roofs over the verandas and were more tastefully carved than those of the chiefs' or common houses (see Figures 4.14 and 4.15)). Similarly, the doors, beams, and ceiling boards of the *oba*'s palace was decorated in a more sophisticated fashion (see Figure 4.15). The snake motif was commonly used in decoration as it represented the power of the *Oba* (Denyer, 1978) (see Figure 4.30). The anterior verandas were constructed as extended porches with columns that bolstered very high pyramidal roof towers or *kobi* (Akinsemoyin & Vaughan-Richards, 1977; Denyer, 1978; Dmochowski, 1990) (see Figure 4.17).

As with the chief's *afin* the kobi were part of the main gable roof of the palace. The king's escorts usually sat under these *kobi.* A highly decorated mud wall went around the palace perimeter and a sizeable portion of palace land (Dmochowski, 1990). A gatehouse was constructed in the perimeter wall and led into the palace's most public courtyard which was usually the largest. The courtyards varied in size; bigger courtyards were used for public meetings, festivals and crafts such as cloth-weaving while the smaller ones were for the king's private use. There was a colonnaded veranda and accompanying rooms surrounding every courtyard (see Figures 4.13, 4.15 and 4.16). Apart from providing access to the apartments, the palace verandas were storage areas for items such as drums and weaving equipment (Ibid). Yoruba palaces had up to 100 courtyards which were much larger than those of ordinary houses. A handful of palaces had their courtyards paved with potsherds and quartz pebbles (Denyer, 1978).

All the courtyard house-types shared similar construction (Adeokun, 2013). In traditional Yorubaland, mud was the major building material (Denyer, 1978; Dmochowski, 1990; Jiboye & Ogunshakin, 2010). Unlike other tribes, such as the Hausa and Sudanese, the Yoruba did not make mud bricks (Denyer, 1978). Instead they used a process called swish puddling to prepare mud for building. The process was undertaken during the rainy season. A pit was dug in the ground by taking out the top soil. Then the red clay beneath was broken up into chunks. The chunks were left to be moistened by rain, after which they were crushed or 'puddled' into a paste-like consistency or swish. Afterwards the puddled clay was left in a lump covered by banana leaves, for use in the dry or Harmattan season (Dmochowski, 1990). The structure was built in seven courses each 300 to 500mm high (Akinsemoyin & Vaughan-Richards, 1977). In southern Yoruba towns, the walls were 150 – 310mm thick (Adeokun, 2013) while in the northern towns, the walls were between 3 to 6m high and 30cm to 60cm (300mm to 600mm) thick (Denyer, 1978; Ibid). A course was laid with the mud-paste within one day, left to dry and harden before another layer was added.

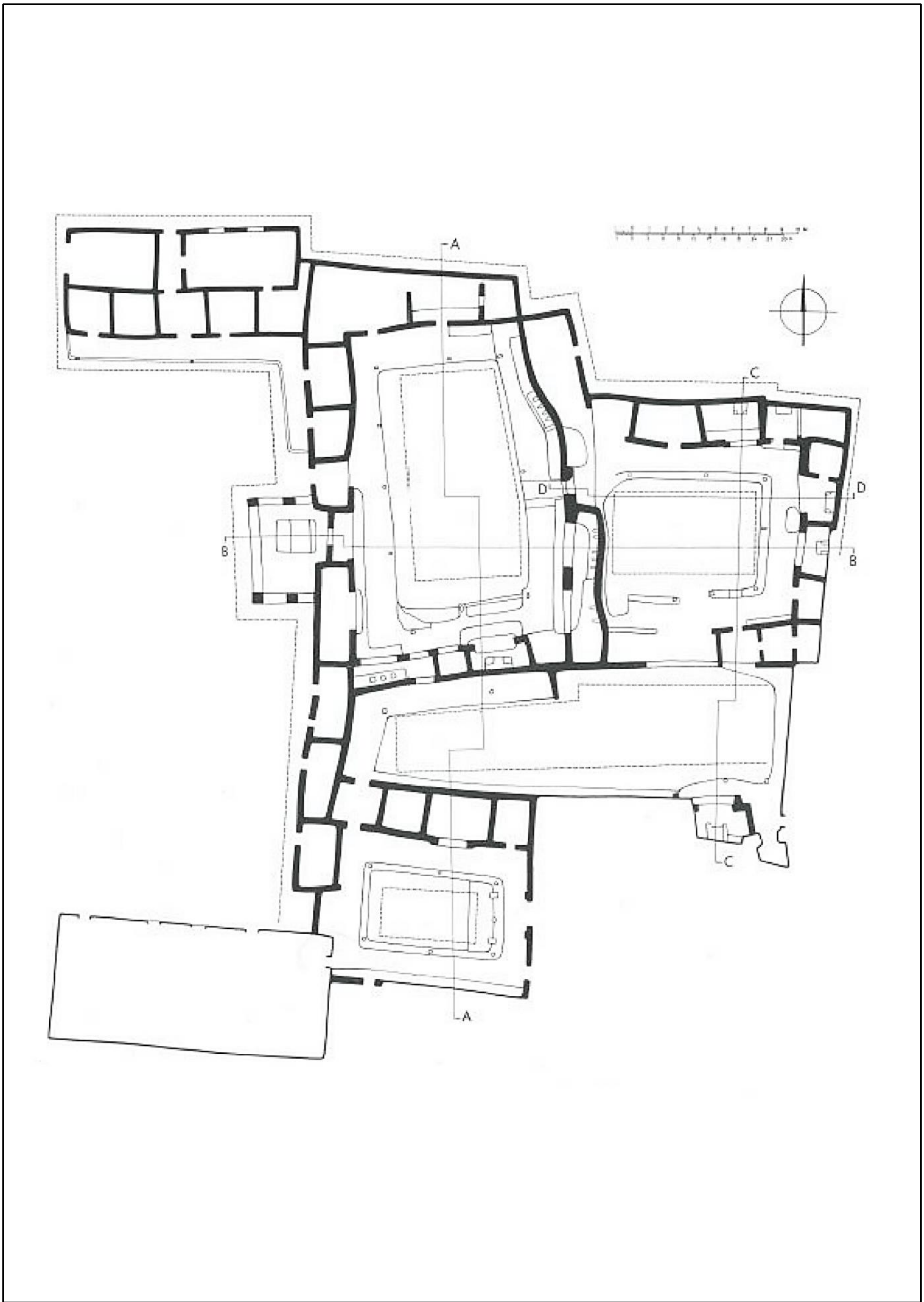


Figure 4.13 *Efon afin* (palace) at Ife – notice multiple large courtyards; source: Dmochowski (1990, p.2.24).

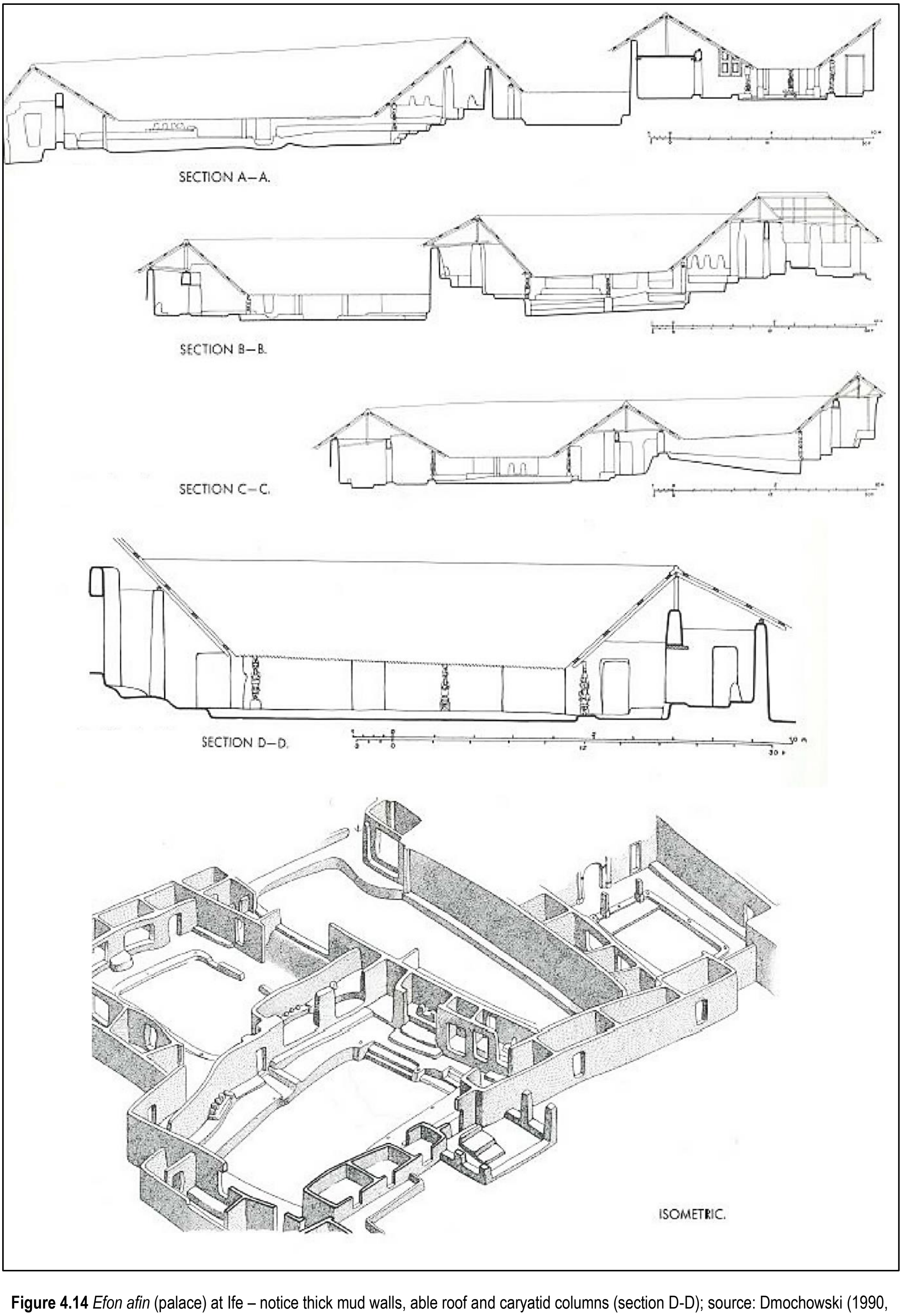


Figure 4.14 *Efon afin* (palace) at Ife – notice thick mud walls, able roof and caryatid columns (section D-D); source: Dmochowski (1990, pp.2.25-2.27).

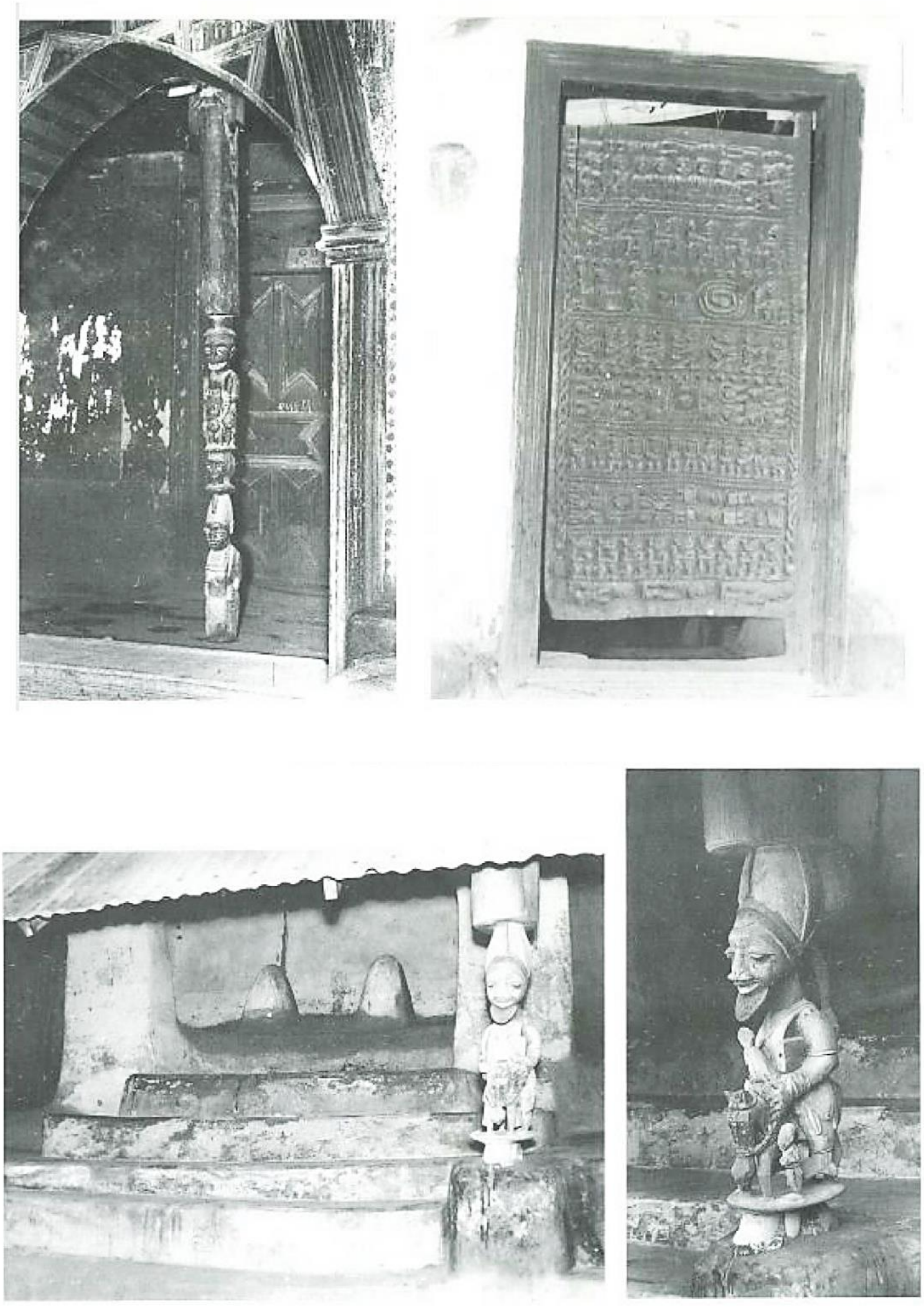


Figure 4.15 *Efon afin* (palace) at Ife – notice caryatids (elaborately carved columns; caryatid below is flanking the king's throne) and carved doors; source: Dmochowski (1990, p.2.24).

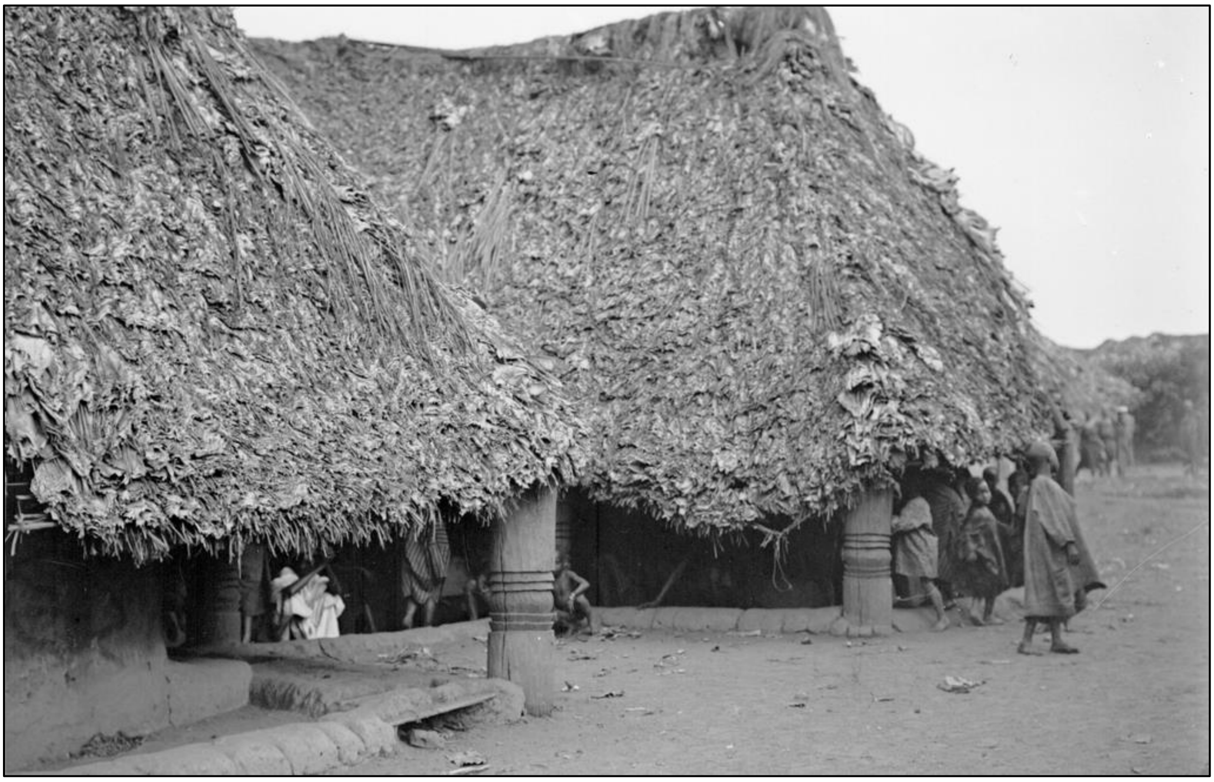


Figure 4.16 Interior view of royal courtyard of an Ife palace – notice characteristic thatch roof and ornamental timber columns and mud walls; source: Frobenius-Institut, Frankfurt am Main, FoA 04-5030, undated.

Figure 4.17 Oluwo's palace at Iwo – notice the *kobi* signifying the social relevance of the palace; source: The National Archives UK, CO 1069-80-37 “Nigeria” undated.

As such this part of the process had to be undertaken in the dry season (Adedokun, 2014b). Alternatively, a mould was made from two rows of framework; the mould was filled with swish and then covered with plaster. This process was used in building the Yoruba house-types except the palace (Denyer, 1978). The *oba*'s palace was always built with a more intricate process involving puddling the mud with palm oil not water (Ibid).

After it was erected, a new wall was sandpapered with half of a coconut shell. Then a mix of thick red earth was applied to the wall surface with rotten banana leaves. Alternatively, the wall was buffed with a mix of blended oil seed tree leaves or with a tint from the locust bean (Dmochowski, 1990). The interior mud walls were plastered with a mix of mud and cow dung to fend off pests such as jiggers (Ibid). To ensure its durability, the external mud wall's plastered surface needed regular renewal as it was exposed to weather (Denyer, 1978; Lloyd, Mabogunje & Awe, 1967). The plastered surface was washed frequently to give it a hard and shiny surface. The floors were made with mud (Lloyd, Mabogunje & Awe, 1967). When the mud floor was properly constructed it had a smooth finish and was as hard as cement (Denyer, 1978). The floor was hardened by pounding the mud with a wooden pestle while it was solidifying. Women would renew the floor regularly using a mix of mud and dung or with indigo slag from cloth-dying (Lloyd, Mabogunje & Awe, 1967). The saddleback or gable roof consisted of layers of elephant grass thatch

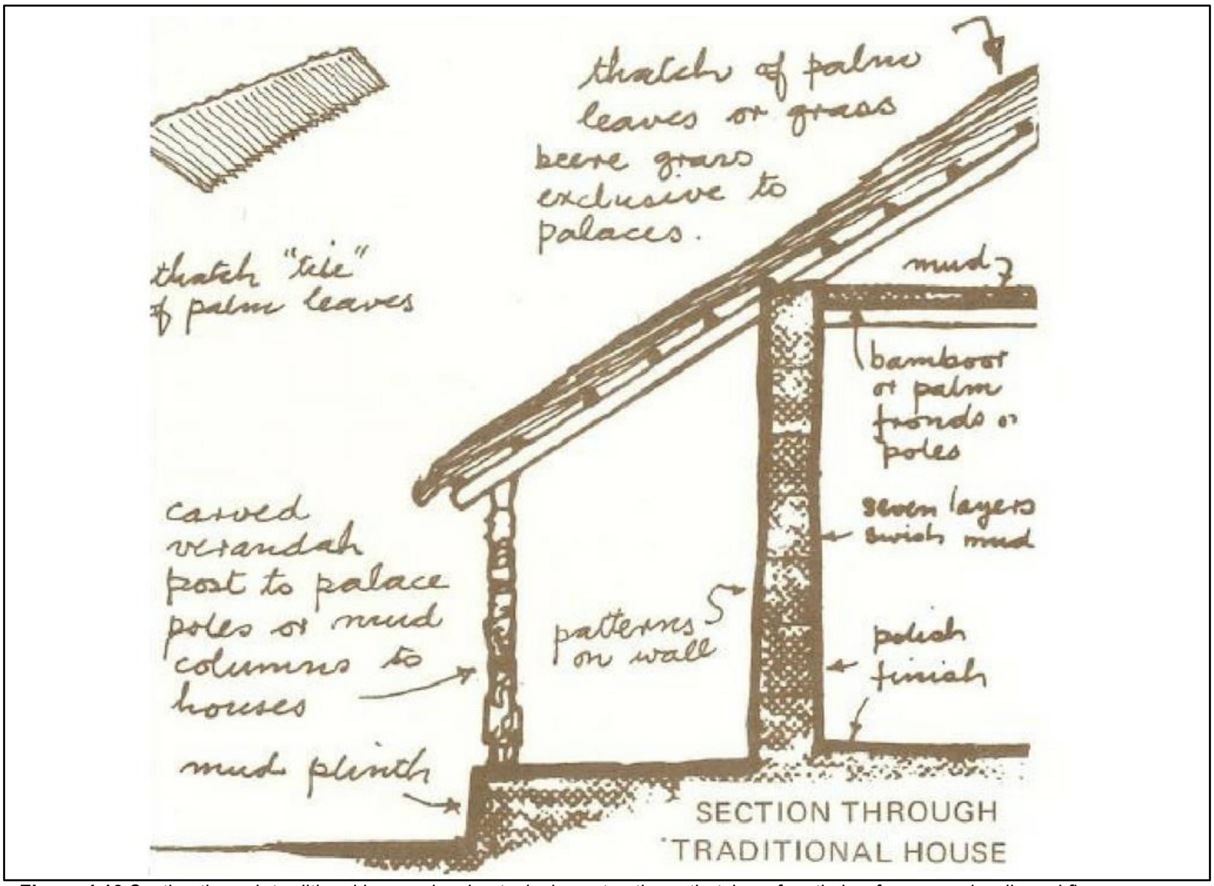


Figure 4.18 Section through traditional house showing typical construction – thatch roof on timber frame, mud walls and floors; source: Akinsemoyin & Vaughan-Richards (1977).

interspersed with cane or wood strips and placed on bamboo or thick raffia palm midrib rafters (Osasona, 2007a; Adedokun, 2014b). The thatch of *Beere* grass was used only for palaces (Akinsemoyin & Vaughan-Richards, 1977). It was supported by timber wall plates, which were supported by forked posts embedded in the walls (Jiboye & Ogunshakin, 2010). Sometimes, the ridge beam rested on forked posts, but it usually was supported by the gable ends; tie beams were not commonly used. The roof frame was covered in leaf or palm thatch, which facilitated easy water drainage. Atolagbe (2010) mentions that construction from foundation to head course was usually undertaken at five-day intervals while the entire house was completed within two-three months. Figure 4.18 shows the typical envelope of traditional Yoruba housing.

The above discussions demonstrate that the traditional house-types in Yorubaland were varied in terms of location and socio-economic status of the occupants. However, research has shown that the courtyard house-type is the accepted form of Yoruba traditional housing as it was the most widely-used in Yorubaland (Jiboye & Ogunshakin, 2010; Osasona, 2007a; Adeokun, 2013; Denyer, 1978; Dmochowski, 1990; Okeyinka & Odetoye, 2010; Adeniji & Ogundiji, 2009). Moreover, it reflected the extended family structure which formed the basic unit of the traditional Yoruba society. Thus, the basic courtyard layout was used to create more sophisticated housing expressions as appropriate to the socio-economic level of the occupants. Other forms, such as the oblong huts and stilted houses of pre-colonial Lagos, were created based on the peculiar economic and geographical features of the location. For instance, the stilted houses were found on the lagoon shores of Lagos while in the inland areas, the courtyard house was the typical form of housing (Akinsemoyin & Vaughan-Richards, 1977). Therefore, the courtyard house-type-expressed in the commoner's house, the chiefs' and kings' courtyard palaces-represents Yoruba indigenous housing. The traditional housing of the Yoruba remained this way until contact with the West in the eighteenth and nineteenth centuries.

4.2 Adjustments activated – South-west Nigerian housing between 1900 to 1952

External influences which affected the south-west Nigerian housing landscape started around the nineteenth century (Akinsemoyin & Vaughan-Richards, 1977). Traditional architectural styles from other countries gained entrance into Yorubaland. These foreign styles blended with Yoruba traditional styles creating a hybrid, semi-traditional class of south-west Nigerian architecture. The semi-traditional style reflected the beginnings of the early colonial period: the first contacts with Western civilisation (Ibid). The introduction of these foreign styles was indirectly facilitated through the slave trade. When the French began the abolition of slave trade in the late nineteenth century, Yoruba slaves retraced their roots and returned to south-west Nigeria in 1840 (Dmochowski, 1990). They settled in Lagos, Badagry, Ibadan and Abeokuta as well as the neighbouring Yoruba towns. There were two types of migrants (Ibid; Osasona, 2007a; Uduku, 2014). The first were the freed Yoruba slaves from Brazil, Cuba and the West Indies; they were called the *Agudas* (*aguda* is the Yoruba word for 'catholic') (Osasona, 2007a). Once they were freed they merged their wealth and hired a ship which took them to Lagos (Akinsemoyin & Vaughan-Richards, 1977; Osasona, 2015). The *Amaros* were likened to the *Agudas*, as the former had returned to West Africa from Cuba (Ibid). The Agudas had learned the skill of bricklaying and carpentry. Osasona (2007a) adds that they were master craftsmen, specialising in stucco work. Furthermore, the *Agudas* were catholic and thus, they built many of the Gothic-style churches and villas for affluent merchants in Lagos.

The second group were the *Saros* who were freed slaves from Sierra Leone (Osasona, 2007a; Uduku, 2014). The *Saros* earned Western education and culture. Hence, the name *Saro* was borne by educated families who traced their origins to Western Nigeria. They were freemen, relieved of their chains on the High Seas or in America. The *Saros* chose of their own free will to return to Western Nigeria after discovering their Yoruba roots (Uduku, 2014). As these migrants settled in south-western Nigeria, they produced architecture that reflected their unbroken attachments to their traditional roots and acquired appreciation for the colonial expression of Portuguese architecture (Ibid; Osasona, 2015). The resulting style has been termed Brazilian or Afro-Brazilian (Dmochowski, 1990; Immerwahr, 2007; Osasona, 2015). The original Brazilian style houses are referred to as the first-generation Brazilian houses, because they were built in Lagos (the initial base of Brazilian repatriates) before being copied by indigenes in other Yoruba settlements (Osasona, 2015). The *Agudas* and *Saros* who settled in Lagos took over Portuguese Town and populated other districts within the city such as Isale-Eko (Akinsemoyin & Vaughan-Richards, 1977; Osasona, 2007a). Portuguese settlers founded Portuguese Town when they arrived in Lagos for trade; they built their Brazilian style houses in this region. However, on arrival in Lagos, the immigrants initially lived in mud houses with roofs of palm leaf thatch (Akinsemoyin & Vaughan-Richards, 1977). This was due to the high cost of imported building materials and the indigenes' lack of skill.

However, as the *Agudas* and *Saros* prospered, they were able to afford imported building materials. According to King (1984), cement, reinforced concrete and corrugated iron were common imported building materials of the early colonial period. King (1984) additionally reports that in 1862, European traders asked the British Governor to replace the thatch roofs of the indigenous houses with less flammable material. In 1877, another request for the replacement of thatch roofs with corrugated iron was made. Although these requests were turned down, the use of corrugated iron became more common. However, Akinsemoyin & Vaughan-Richards (1977) state that thatch roofing was replaced with iron sheets when the British Government ordered a replacement of the thatch roofs with iron covering in 1861. Despite these seemingly conflicting accounts, it is evident that imported western materials became more common than traditional materials. Accordingly, the immigrants started building better houses. In 1857, a Sardinian called Scale started brick-making and tile-making (Ibid). King (1984) adds that mud walls were replaced by brick; the Western missionaries built one of the two brick kilns established in Lagos in the 1860s. Thus, the Agudas and Saros were able to build single-storey and multi-storey houses depending on their level of wealth. These were the first-generation Brazilian houses. According to Lloyd, Mabogunje & Awe (1967), they displayed a high level of ornamentation such as baroque balusters and floral designs on doorposts, bas-relief embellishments on lower halves of exterior walls and occasional parapet walls (see Figure 4.19). A typical house of this type had four rooms next to one another, each room opening into an anterior and posterior veranda (Osasona, 2007a; Ibid). The kitchen was detached and located across a courtyard which accommodated the lavatory and other structures. The courtyard was fenced round and measured 80m by 34m typically. After 1880, the Saros became very wealthy and the quality of their housing improved and Akinsemoyin & Vaughan-Richards (1977) illustrates an example of their housing.

The wealthy Saro typically lived in a two-storey house with perimeter dimensions of 11m by 5.5m and a height of 6m. Each floor was about 2.7m high. The layout consisted of a front and rear veranda, each 2.4m wide with five large windows each. There were four different windows of dimensions 1.4m by 1m which were split in the middle and spread between the two storeys. The first floor had a bedroom and large lounge. The roof was part of the second floor where the family slept. The walls were heavyweight construction (ranging from burnt brick to concrete blocks), were white washed and interiorly and exteriorly plastered. The first floor had finished timber flooring and the roof was covered in corrugated iron sheets on timber frame. The more prosperous Saros were merchants or professionals and built luxurious houses which towered above neighbouring houses (see Figure 4.19). The fabrics of these houses were similarly made of brick or concrete block, timber flooring and corrugated iron roofing (see Figures 4.19, 4.21 and 4.22). Furthermore, the houses of the merchants were characterised by the commercial use of the ground floor rooms as shops and offices (Osasona, 2007a) (see Figure 4.20). These merchant houses may be likened to the colonial south-east Asian shophouses of Singapore, Thailand and China, whose ground storeys provided shop spaces (Home, 1997). The European (English, German, Austrian and Italian) traders built similar two-storey houses with extended timber balconies on the upper floor, in compounds. When European companies set up in Lagos, they erected similar two-storey houses; this type did not have extended balconies but many staircases and well-managed spaces.

The copies of the first-generation Brazilian houses have been termed ‘second-generation Brazilian houses’ with the ‘Afro-Brazilian’ style (Osasona, 2015). The Afro-Brazilian style houses displayed less ornamentation and number of spaces than the originals (Osasona, 2007a) (see Figures 4.23 and 4.25).

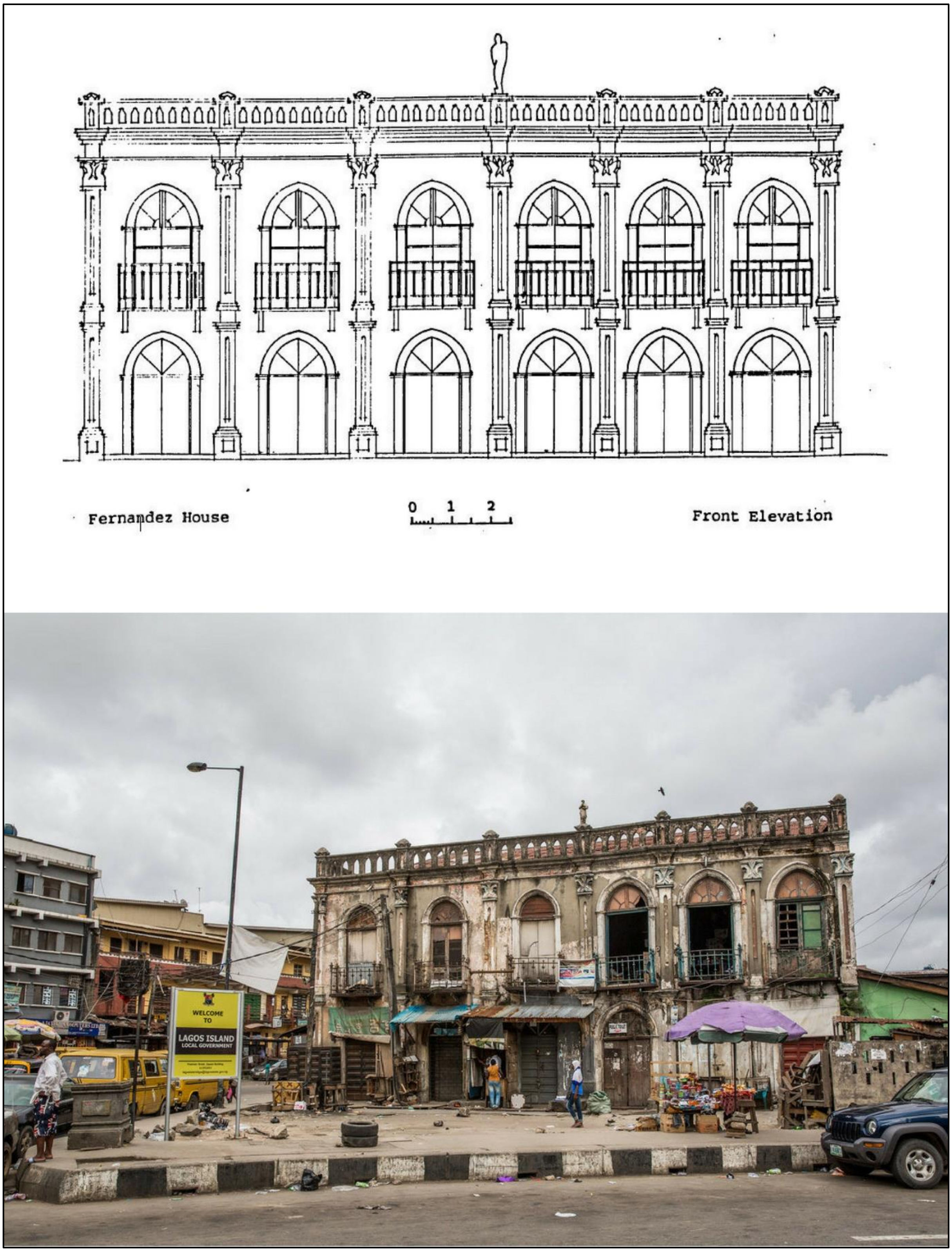


Figure 4.19 First generation Brazilian residential architecture – the two storey Fernandez House (Casa do Fernandez) built in 1846 and formerly at 6 Tinubu Square, Lagos but now demolished; source: Alonge (1994, p.266) – top image, Legacy 1995 – bottom image).

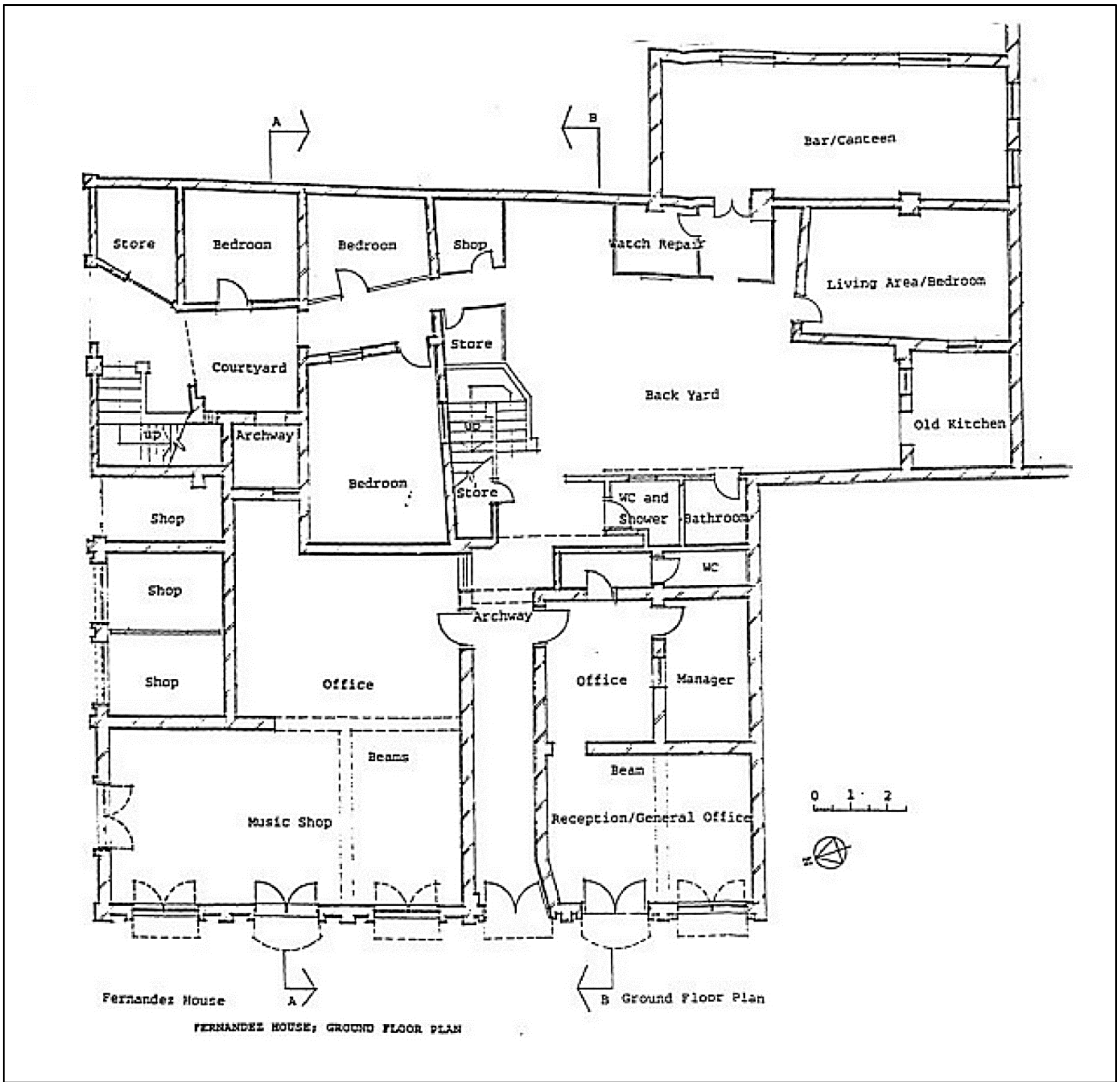


Figure 4.20 First generation Brazilian residential architecture – ground floor plan of the Fernandez House showing the spatial morphology – notice the commercial functions of the anterior spaces; source: Alonge (1994, p.267).

The Afro-Brazilian style houses were built in other Yoruba towns such as Ile-Ife and Ibadan (Lloyd, Mabogunje & Awe, 1967; Osasona. 2015). A typical Afro-Brazilian house had the classic central corridor or *passagio*, with rooms on either side (see Figure 4.23). The construction featured heavy burnt brick walls with sand-cement render; hardwood for timber flooring, stairs, door and window frames and roof members (Ibid) (see Figures 4.23 and 4.24). Stucco was commonly used to mould window hood brackets, murals and balusters (Osasona, 2007a) (see Figure 4.24). Through this indirect transfer, the Brazilian style influence spread across Yorubaland.

However, there was a direct transfer of the Brazilian style. In the early 1500s, Portuguese missionaries brought Christianity to Yorubaland; they had the most significant interaction with Yoruba community in Lagos (Adogame, 2010). However, they let economic and political interests supersede their original intentions and their missionary efforts failed (Ibid). Still, the Portuguese brought great wealth and their

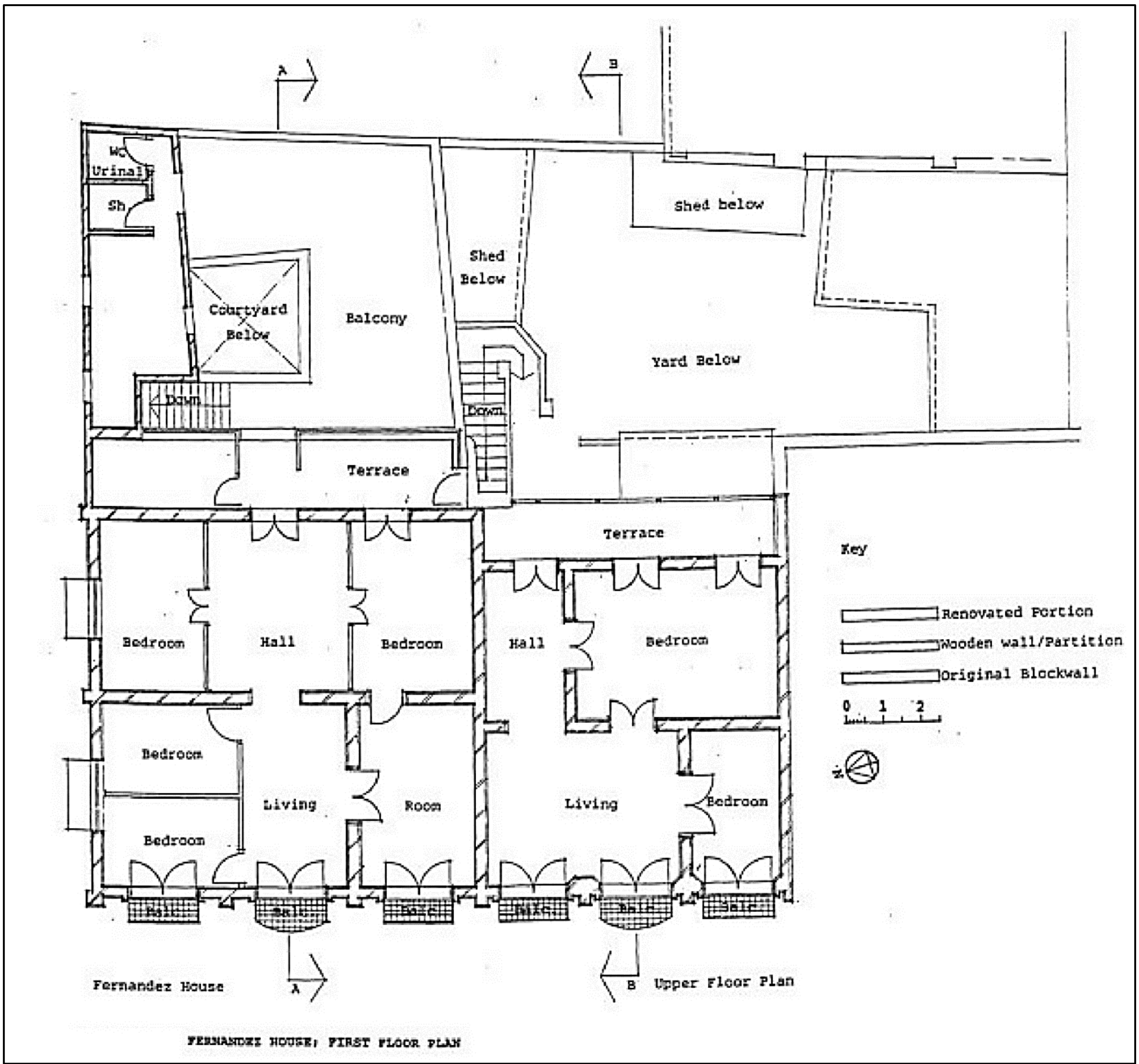


Figure 4.21 First generation Brazilian residential architecture – first floor plan of the Fernandez House showing the spatial morphology – notice the courtyard space; source: Alonge (1994, p.268).

architecture (Akinsemoyin & Vaughan-Richards, 1977; Dmochowski, 1990) to Yorubaland through dealings with Lagos traditional royalty. In late 18th century during his reign, King Akinsemoyin of Lagos allowed the Portuguese slave traders to turn Lagos into a slave trade centre while the French were attempting to abolish slave trade (Ibid; Ibid). The king had related with the Portuguese when he was still a prince on exile to Whydah (Ibid), a kingdom in the south of today's Benin Republic. Whydah was one of the biggest African slave trade centres during the 17th to 19th century (Norman, 2009). In return, the Portuguese slave traders built the Lagos *afin* for Oba Akinsemoyin in 1705. Hence, the Lagos *afin* or *iga* is an example of the semi-traditional blend of Portuguese traditional architecture and Yoruba traditional housing forms, associated with early colonial south-west Nigerian architecture. Although they financed the construction, indigenous labour built the structure. The Portuguese's only involvement in the design and building process was the provision of pottery roofing tiles (Dmochowski, 1990). The Lagos palace has undergone many changes; however, Akinsemoyin & Vaughan-Richards (1977) give a detailed

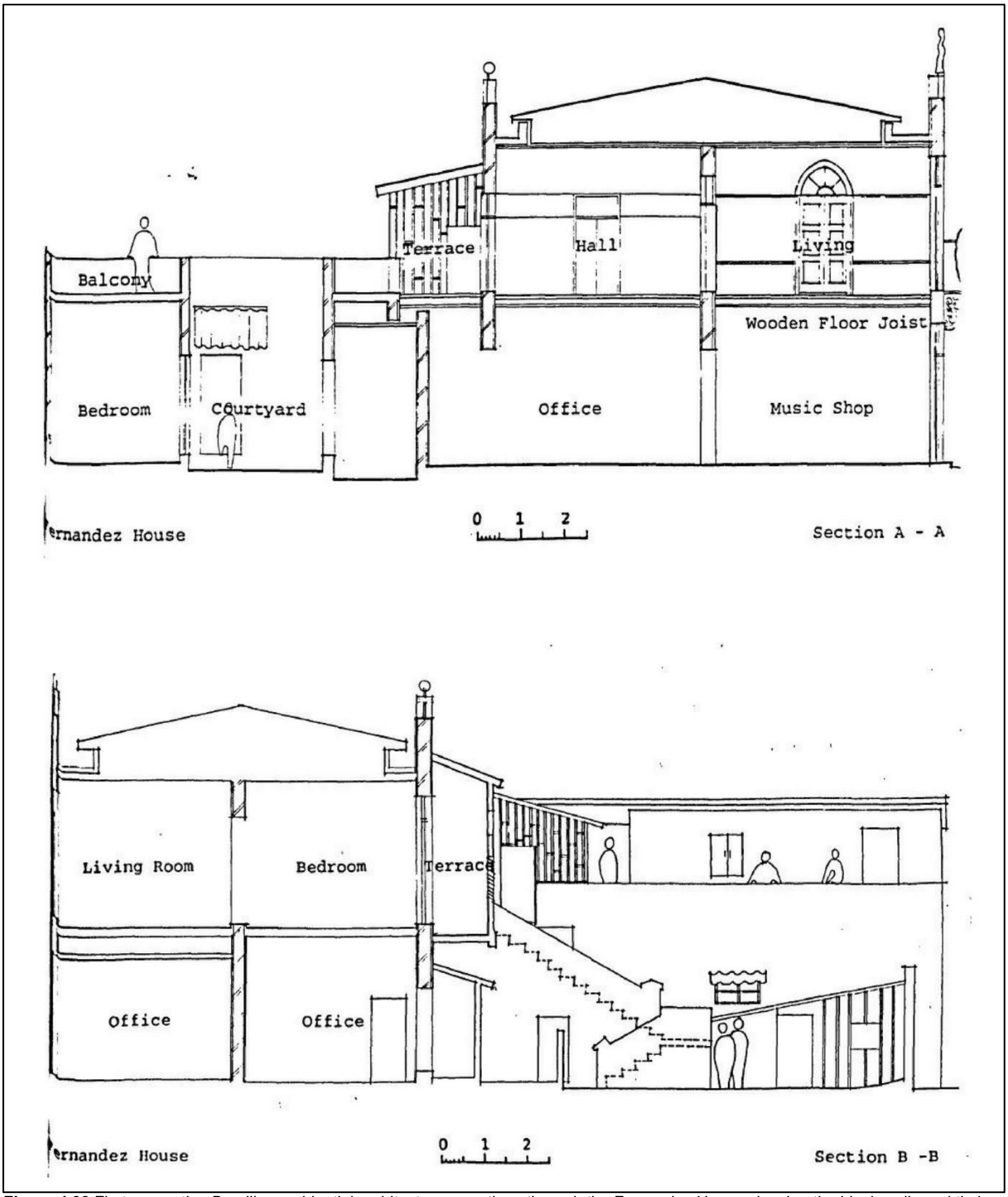


Figure 4.22 First generation Brazilian residential architecture – sections through the Fernandez House showing the block walls and timber flooring; source: Alonge (1994, pp.269-270).

description of the original Lagos palace. It was tailored to the needs of Oba Akinsemoyin: he had many wives, servants and courtiers. The structure was made of materials imported from Portugal: iron columns and tiles for the roof. The tiles were fire resistant and saved the palace from burning down twice. The tiles were later replaced by corrugated iron sheets. The facades featured arches reminiscent of Roman architecture and Portuguese columns. The Yoruba artisans blended the traditional Yoruba patterns with the acquired Roman and Portuguese motifs (see Figure 4.21). Dmochowski (1990) adds that the walls

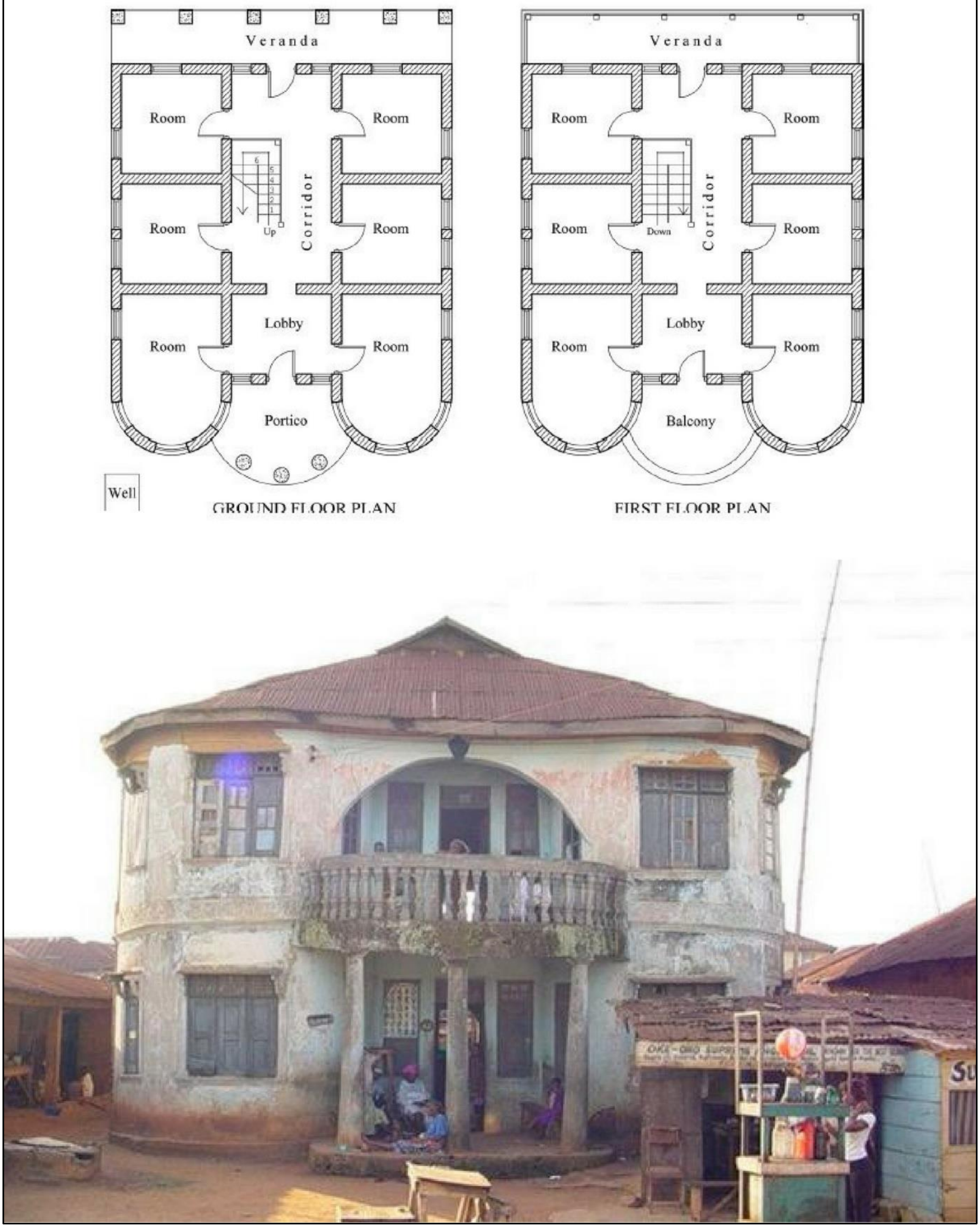


Figure 4.23 Second generation Brazilian residential architecture – Ologbenla House in Ile-Ife, with central corridor, less ornamentation and typical Brazilian envelope construction: corrugated iron roof and heavyweight brick walls; source: Osasona (2015, p.51 (top image), p.50 (bottom image).

Figure 4.24 Portions of the building fabric of Ologbenla House showing timber casement windows, peeled plaster exposing brick wall (first image), timber joists supporting external timber floor (second image) and stucco-based balusters; source: Osasona (2015, p.51 (top image), p.50 (bottom image).

Figure 4.25 Second generation Brazilian residential architecture in Ile-Ife, with less ornamentation and typical Brazilian envelope construction: corrugated iron roof and heavyweight brick walls.; source: Osasona (2007a, p.9).

Figure 4.26 Interior throne-room courtyard of the Lagos *afin* showing Roman and Portuguese features – ornamental pillars, cornices and stucco finishiing; source: Dmochowski (1990, p.2.53).

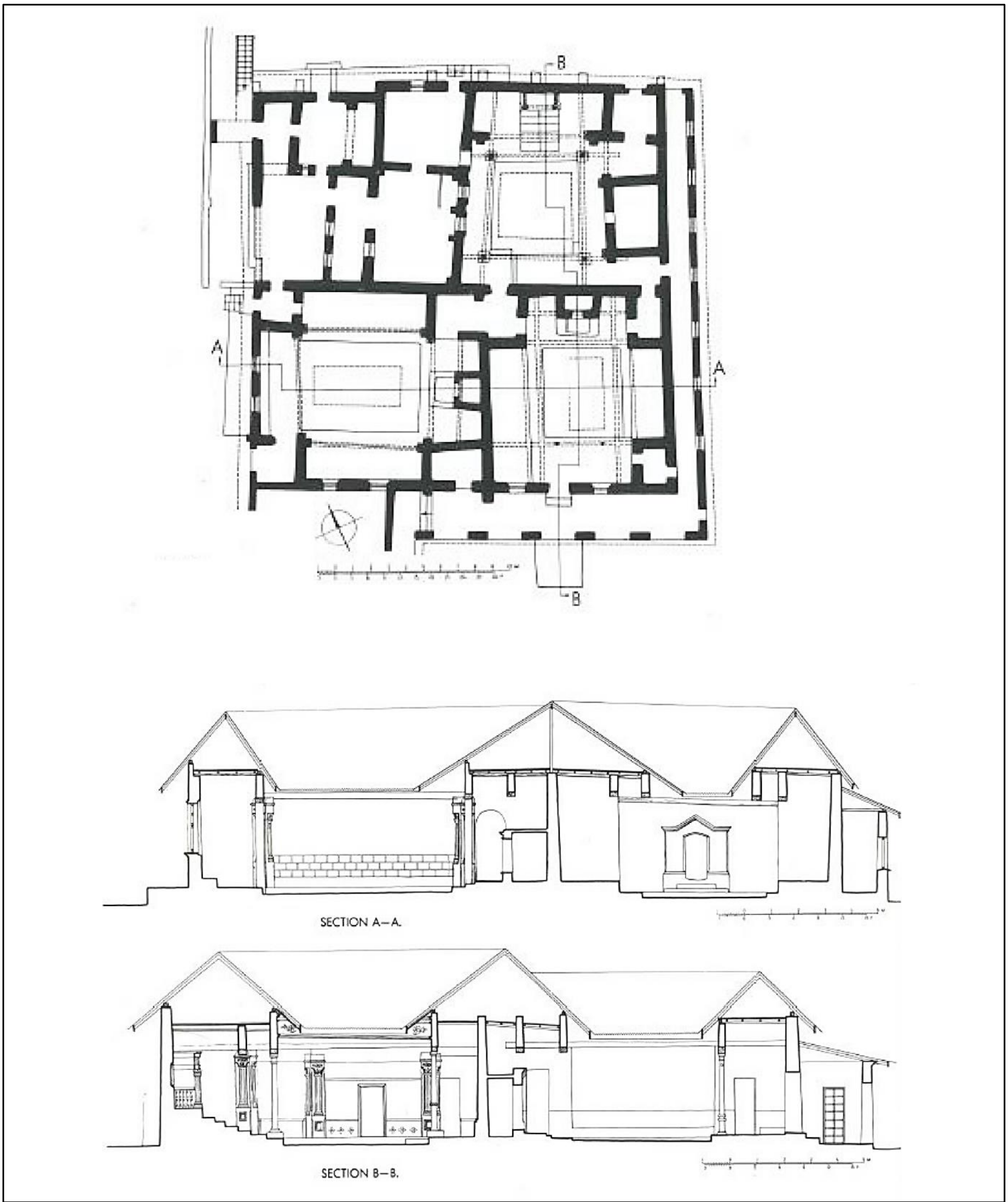


Figure 4.27 Floor plan and sections of the Lagos *afin* – notice thick earth walls; source: Dmochowski (1990, p.2.53).

were built in earth and finished in stucco (see Figures 4.26 and 4.27). There were three main spaces: the Throne Room, Living Room and an interconnection of small cubicles, which formed a dense square of approximately 550m^2. The numerous cubicles served the king, his wives and courtiers. Except the throne room, these main spaces had courtyards with impluvia and surrounding rooms, shrines and tombs of past kings.

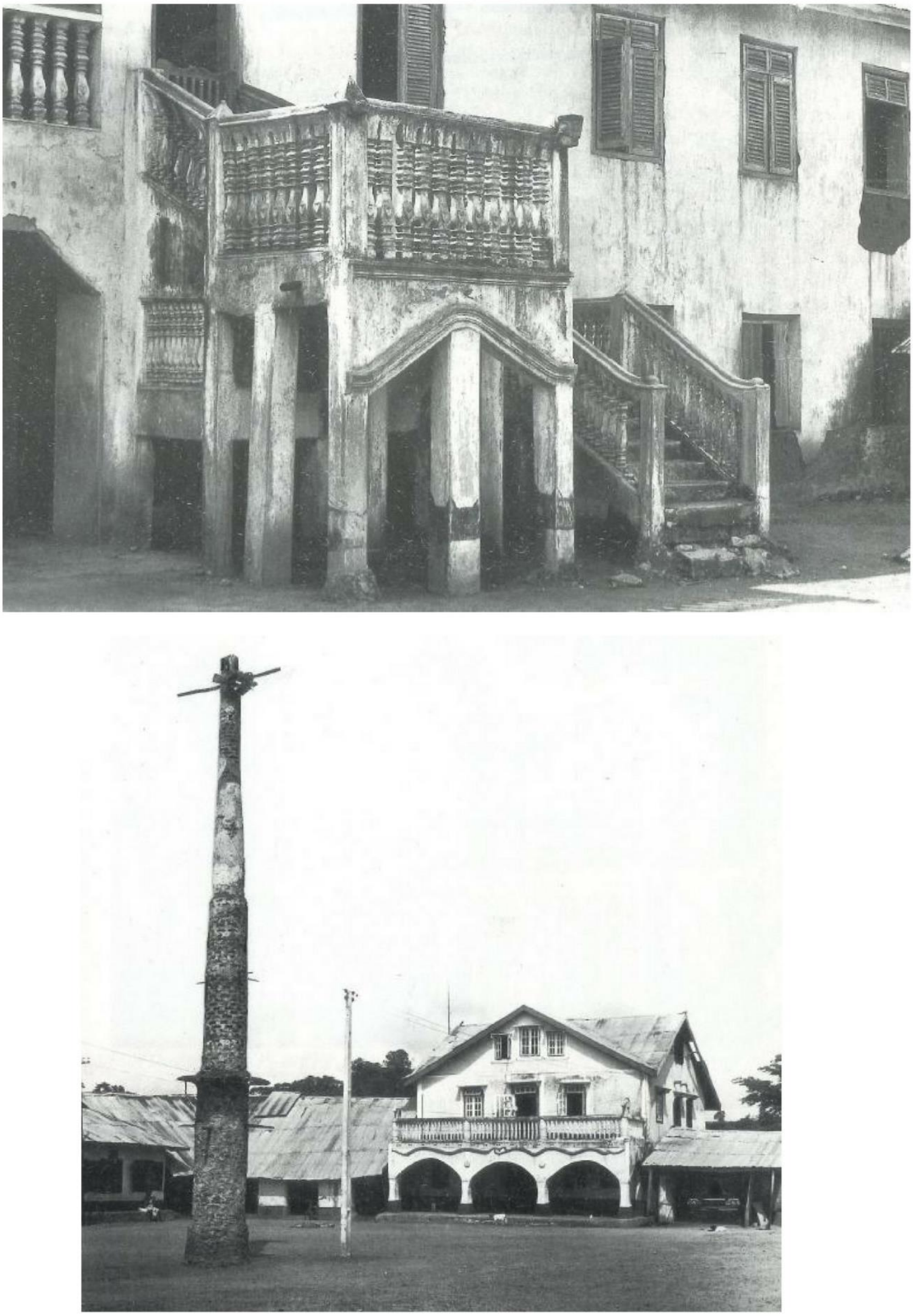


Figure 4.28 The inner side of the *Ikere* palace gatehouse showing the elaborate cement staircase - top image, and the King's dwelling showing Afro-Brazilian features (arches, balustrades, typical construction of corrugated iron roofing and solid heavyweight walls) in the entrance courtyard (*ualila*) – bottom image ; source: Dmochowski (1990, pp.2.38-2.39).

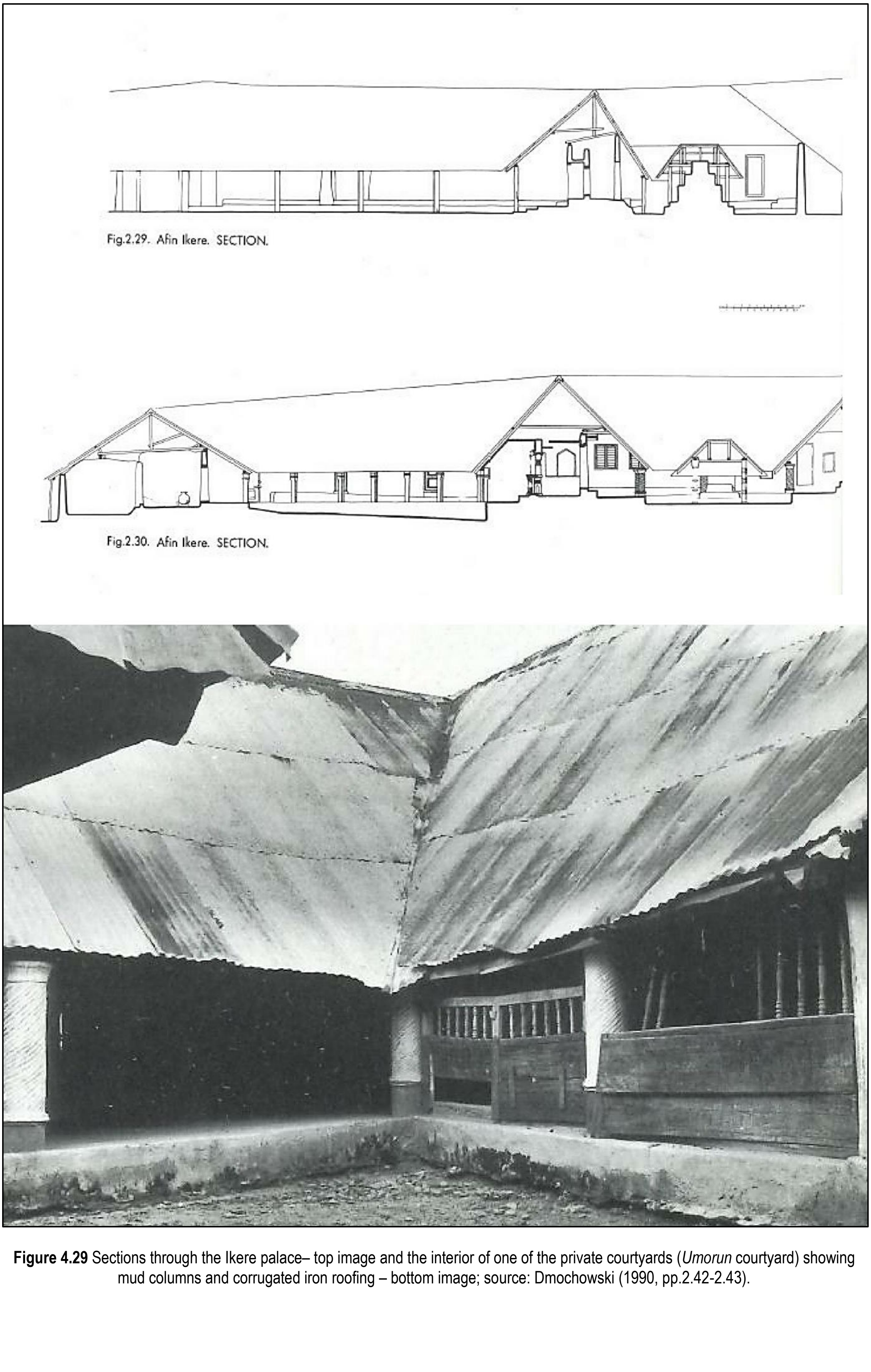


Figure 4.29 Sections through the Ikere palace– top image and the interior of one of the private courtyards (*Umorun* courtyard) showing mud columns and corrugated iron roofing – bottom image; source: Dmochowski (1990, pp.2.42-2.43).

Figure 4.30 A cubicle at the rear of the private *Umorun* courtyard showing mud walls and timber ceiling – notice the snake motif which symbolised the king's authority, over the archway; source: Dmochowski (1990, p.2.43).

However, the original *Iga* deteriorated through time and reductions in royal resources during the subsequent reigns of succeeding Obas (Akinsemoyin & Vaughan-Richards, 1977). Another example of the semi-traditional south-west Nigerian style is the *Ikere afin.* Dmochowski (1990) depicts the history and character of this second-class *afin*. The *Ikere* palace was built on the revered *Olusunta* rock, belonging to the *Olukerre* cult who claim to have migrated from Ife. It is home to the *Ikere* kings or *Ogogas* who allege ties to the *Bini* kingdom. Therefore, the palace was built following the classic Ife *afin* layout but displays Afro-Brazilian character. While most of the courtyards are built in mud (see Figures 4.29 and 4.30), the entrance to the palace is celebrated by a flamboyant, cement-constructed two-storey gatehouse built for *Ogoga Adewoni* a little while before 1851 (see Figure 4.28). As typical with Yoruba palaces, the *Ikere afin* is composed of a series of impluvial courtyards. It has one public courtyard (*ualila*) and four private ones (*Ifa, Umorun, owa-aje* and *kibi* courtyards). Each private courtyard is surrounded by mud columns as well as intricate and highly symbolic caryatids. The gate house leads into the first courtyard, the large *ualila* courtyard which functions as a public meeting place (see Figure 4.28). On the other side of the *ualila* courtyard, opposite the gate, is the king's dwelling. The Afro-Brazilian style royal house was built in 1930 for *Oba Ologunboye*. It has three storeys with most of the rooms on the first and second (attic) floor. The attic seemed to be a common feature of Brazilian residential architecture (Osasona, 2007a). There is a large anterior veranda on the ground floor with three arches and a terrace above. Above the arches are the reliefs of two long snakes and the terrace's balustrade supports three cement sculptures (see Figure 4.30). On the left side of the *ualila* is the entrance to the internal sections of the palace.

The first interior courtyard is the *Ifa* courtyard where *Ifa* priests hold rituals. This courtyard is reported to be very old, existing before the older courtiers (up to 80-year-olds) were born. In this small impluvium, new babies are accepted as reincarnated ancestors and servants can live in the surrounding rooms. Connected to the *Ifa* courtyard is the second private courtyard is *umorun* or *orun* courtyard. The *umorun* is as old as the *Ifa* court and has an irregular shape. The court hall was the third courtyard called *owa-aje* and it was built in 1900 by *Oba Awolodu*. Its trapezoidal impluvium is bounded on three sides by solid rectangular columns. The last court or *kibi* is accessed through the doors in the left posterior wall of the *owa-uje* veranda. The coronation of chiefs held in the *kibi*. The chiefs would carry their staffs, stand before the king and swear their oaths of allegiance. Other chambers around these courtyards are used for ritual and administrative purposes. These chambers and their access doors are very well decorated with traditional motifs. Thus, the *Ikere* palace is a display of the creative blending of Yoruba traditionalism and external influences producing a hybrid, semi-traditional type. Initially, in Lagos, the Brazilian style was demonstrated only in the palace because it was a capital crime for the king's subjects, including his chiefs and advisers, to advance socio-economically (Akinsemoyin & Vaughan-Richards, 1977). Therefore, the spread of the Brazilian style house and its variants, could have been limited across Yorubaland. However, as the Portuguese themselves settled in Lagos and the *Agudas* and *Saros* arrived, civilians were able to build Brazilian style houses.

Around this time (the mid to late nineteenth century), the British had begun to establish a proper colonial government in Yorubaland (Ibid). As the earliest settlers arrived to survey the south-west region before establishing government, they initially attempted many adjustments to the new surroundings and worked with the existing local construction (Home, 1997). Common coloniser dwellings were bungalows built of indigenous materials. Examples of these structures were the Constabulary officer's residence at *Odo Otin* in Osun and the District Engineer's house at *Oloko Meji*, Lagos (see Figures 4.31 and 4.32). The common building envelope comprised of walls built of timber poles tied together, thatch roof and timber or mud flooring. Sometimes, the houses were raised on stilts as in the case of the Constabulary officer's residence at Odo Otin. These early colonial European houses were unofficial buildings marking the beginnings of British colonisation. However, as they established their colonial administration, European colonial housing became more diverse and displayed more European influences. When the British re-introduced Christianity into the region, the colonial mission houses were built (Adogame, 2010).

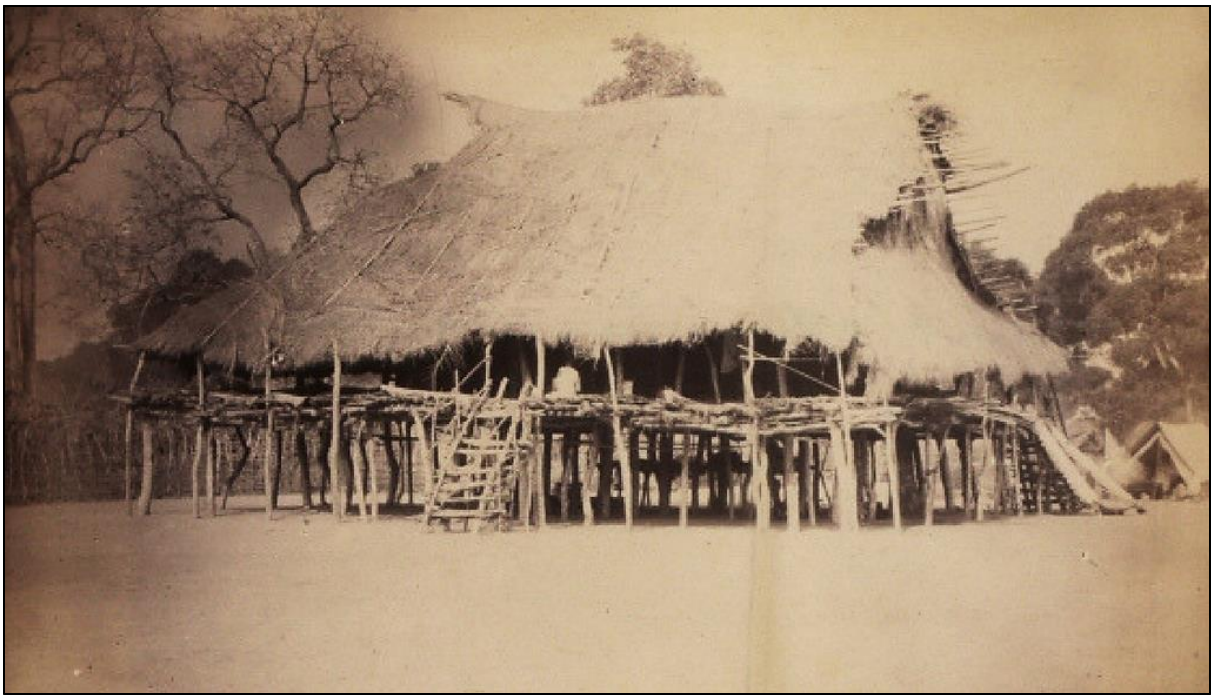


Figure 4.31 Constabulary officer's residence at Odo Otin in Osun, showing stilted timber frame and thatch roofing; source: The National Archives UK, CO 1069-80-49 "Nigeria" undated.

Figure 4.32 District Engineer's house at Oloko Meji, Lagos, showing stilted timber frame and thatch roofing; source: The National Archives UK, CO 1069-80-62 "Nigeria" undated.

Figure 4.33 Agege mission station on the road to Abeokuta – building fabric is largely made of timber-thatch framing with thatch roof covering; source: The National Archives UK, CO 1069-78-39 "Nigeria" undated.

Figure 4.34 The 1842 mission house built in Badagry, Lagos – building fabric consists of brick external walls and corrugated iron roof; source: NTA (2016).

Figure 4.35 Inside the 1842 mission house built in Badagry, Lagos – first picture show timber partition wall, timber floor joists of the suspended first floor supported by the external brick wall, second picture is a close-up of timber floor joists of the suspended top floor and third picture shows timber stair case leading to the first-floor level; source: NTA (2016).

The colonial mission houses accommodated the British missionaries, who had a significant role in introducing European architecture and culture, especially based on health (King, 1984). According to Akinsemoyin & Vaughan-Richards (1977), the mission house-type typically had timber framed walls and floors with corrugated iron roofs; however occasionally, external walls were made of brick (see Figures 4.33, 4.34 and 4.35). It was the European missionaries who built the first metal roofs in Ibadan (King, 1984). Venetian shutters were installed in the windows of the walls. The house's lower floor was usually used for storage and as office space; sometimes it would be left open. The living and sleeping rooms were on the upper floor and surrounded by a veranda walled by venetian shuttered windows. The shutters had to be closed at least twice a day and most of the wet season. The missionaries used the verandas as living areas as the interiors were dark. The houses of the earliest government officials such as the old Government House in Lagos and Surveyors Quarters in Lagos, were built around this time (Akinsemoyin & Vaughan-Richards 1977). They had a character similar to the mission houses. Timber was the predominant construction material. Windows were timber and were commonly vertical sliding sashes or side hung jalousies with a top hung lower section (Ibid). However, some parts of the house's frame were built of more solid material such as cement or brick. Furthermore, the space syntax was akin to that of the mission houses (Ibid). The living spaces were placed on the second floor of the two-storey versions, while some others had one floor raised on stilts.

However, as the British colonial government acquired a more formal structure, more European colonisers moved into the colonies to explore opportunities. These early colonisers lived in rooms (King, 1984). The rooms were the barrack accommodation which Chang (2015) refers to as the first formal British colonial tropical building type. Chang (2015) explains that in the mid-1800s, a standard design was developed for the British colonial barrack buildings. Thus, the barracks were originally designed to serve soldiers in colonial armies (Home, 1997). The spaces provided included offices, stores, dining rooms, study rooms located on the ground floor while the sleeping areas were on top floors. Beds were positioned between fenestrations. The heights and sizes of the barrack spaces were continuously modified. Furthermore, barrack housing became the most popular form of colonial worker accommodation. Consequently, it was modified to suit the lifestyle of the workers. Home (1997) expatiates that the modified design was adapted to provide housing for single workers without families. This house-type was also called the barrack range, the hostel, the barrack yard or the coolie lines (Ibid). The typical barrack was single-storey with a long and narrow layout. The plan provided a single or double row of rooms, measuring approximately 3m by 4m each. A passageway ran through the length of the barrack; occasionally it was open on one side for ventilation. Each room was designed to accommodate up to six workers. Communal spaces were provided for cooking, laundry and hygiene; they were typically arranged at one end of the building. The

Figure 4.36 Barracks at Ibadan – building fabric is made of timber and fibre-mat walls with thatch roof covering; source: The National Archives UK, CO 1069-80-32 "Nigeria" undated.

building's structure was largely composed of timber and cast-iron framing. Soyinka (1994) and Livsey (2014) mention an example of barrack accommodation in south-west Nigeria. The barrack accommodation of *Eleyele*, Ibadan were used for a military hospital (Livsey, 2014). The dilapidated huts later served as the first physical structures of the University of Ibadan. The University of Ibadan started as Yaba College founded in 1932 at Yaba, Lagos. The institution was moved to *Eleyele*, Ibadan; it became Nigeria's first University College. The student accommodation was provided with the dilapidated huts made of concrete floors, timber walls and thatch roofs, divided into small rooms with fibre-mat partition walls (Soyinka, 1994; Ibid) (see Figure 4.36). These structures were easily flooded as rain leaked through the walls. Two to four students stayed in one of such rooms and overcrowding was easy. The dormitories were linked to other facilities such as the common and reading rooms, library by roofed walkways. However, as the University barracks show, overcrowding and unsanitary conditions were typical of barrack accommodation. Hence, when the wives of the European officials joined them in their barrack rooms, they were appalled by the unsanitary conditions (King, 1984).

Differently, the wealthier colonisers built houses with their knowledge of European construction to indicate their success (Prucnal-Ogunsote, 1993; Home, 1997). As such, portable Georgian-style country houses with iron envelopes were imported and constructed. However, they found these houses to be too hot, expensive to build and maintain (Ibid). Accordingly, the unsanitary barracks and inappropriate country houses initiated a demand for better housing for the colonisers. This demand was met by the work of the

Public Works Department (PWD) (Ibid). The PWD became active in 1896 when a director was appointed to run the Department (Akinsemoyin & Vaughan-Richards, 1977; Salami, 2016). Its headquarters was in Lagos and it had developed from the Surveyor General's department (Bigon, 2006; Salami, 2016). Salami (2016) explains that the PWD was a feature of development across the British Colonies; its success in India inspired the Department's establishment in other colonies including Nigeria. Thus, the PWD was active in tropical colonies and employed British architects who had trained in the Royal Engineers School (Crinson, 2003; Salami, 2016). The PWD architects designed public buildings and housing projects. As the PWD addressed the colonisers' housing problems, the housing projects were conceived to create healthier and cleaner living environments (King, 1984). The bungalow was the major PWD housing form; King (1984) states that it was regarded as the best form of tropical housing. Additionally, although the number of storeys varied, the bungalow was detached with a definite number of functional spaces (Ibid).

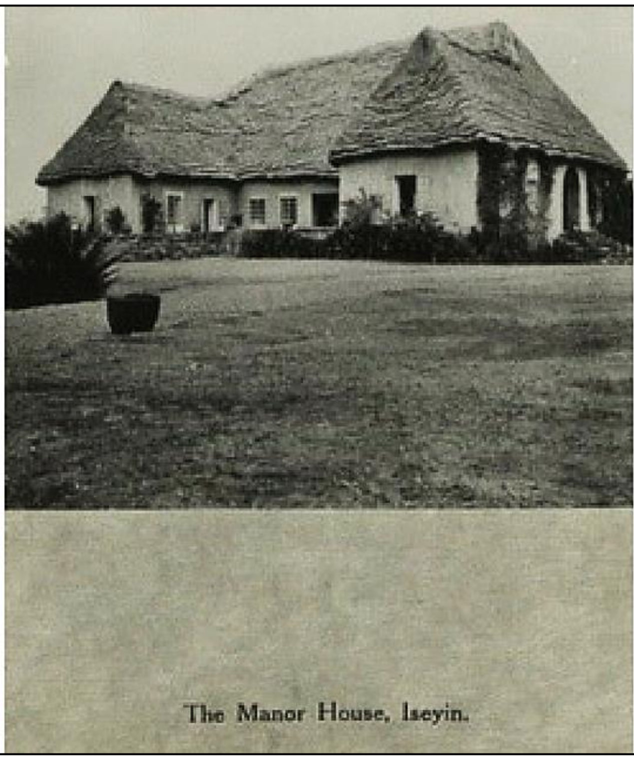


Figure 4.37 Colonial Manor house at Iseyin, Oyo State which bears similarities to an English Country house; source: The National Archives UK, CO 1069-65-67 "Nigeria" undated.

Accordingly, the PWD bungalows provided the European officials with better housing. The PWD houses were solid structures with strict geometric forms; they ranged from bungalows to multi-storey villas, some of which resembled English country houses (Mabogunje, 1962; Akinsemoyin & Vaughan-Richards, 1977) (see Figures 4.37 and 4.39). The PWD considered climate-responsiveness and local construction (Jackson & Uduku, 2016). The houses of the PWD had large overhanging eaves over colonnaded verandas (see Figures 4.39 and 4.41).

Figure 4.38 Colonial house built in PWD design but with indigenous construction – notice mud finishing of external walls, timber frame for veranda and corrugated iron roof; source: The National Archives UK, CO 1069-65-67 “Nigeria” undated.

Figure 4.39 1908 PWD European house in Lagos (all materials were imported) – notice large overhanging eaves and colonnaded veranda; source: Fry & Drew (1956).

Figure 4.40 1920 PWD Engineer's Quarters in Abeokuta – notice large overhanging eaves, veranda and building fabric: solid cement block wall, corrugated iron roofing; source: Salami (2016, p.241).

Other types showed indigenous construction built by local labour, with mud finishing and projecting roofs (Ibid) (see Figure 4.38). With a restricted range of materials and construction technology, the PWD designs were in types which exhibited variations in number of storeys and form. For example, the 1925 PWD bungalow type T17A had a suspended floor and roof vents (see Figure 4.41). Another example is the 1938 PWD house-type C which was one of the first houses to have a concrete flat roof (Akinsemoyin & Vaughan-Richards, 1977). Common materials were timber, brick, concrete, stone, corrugated iron and reinforced concrete. However, the PWD bungalow was a standard design (Ibid; King, 1984; Jackson & Holland, 2014). The typical PWD coloniser bungalow had timber, brick, concrete or stone frames raised on reinforced concrete or wooden pillars (1.2m to 2.4m high) (King, 1984; Jackson & Uduku, 2016). The roof had a metal (corrugated iron) cover supported by roof trusses. It was very spacious with many large windows and a wide veranda which occasionally went round the house's perimeter. The windows were wooden casement shutters. Mosquito proofing was installed on the verandas and windows to prevent contraction of malaria (Salami, 2016). Large overhanging eaves covered the veranda (Ibid).

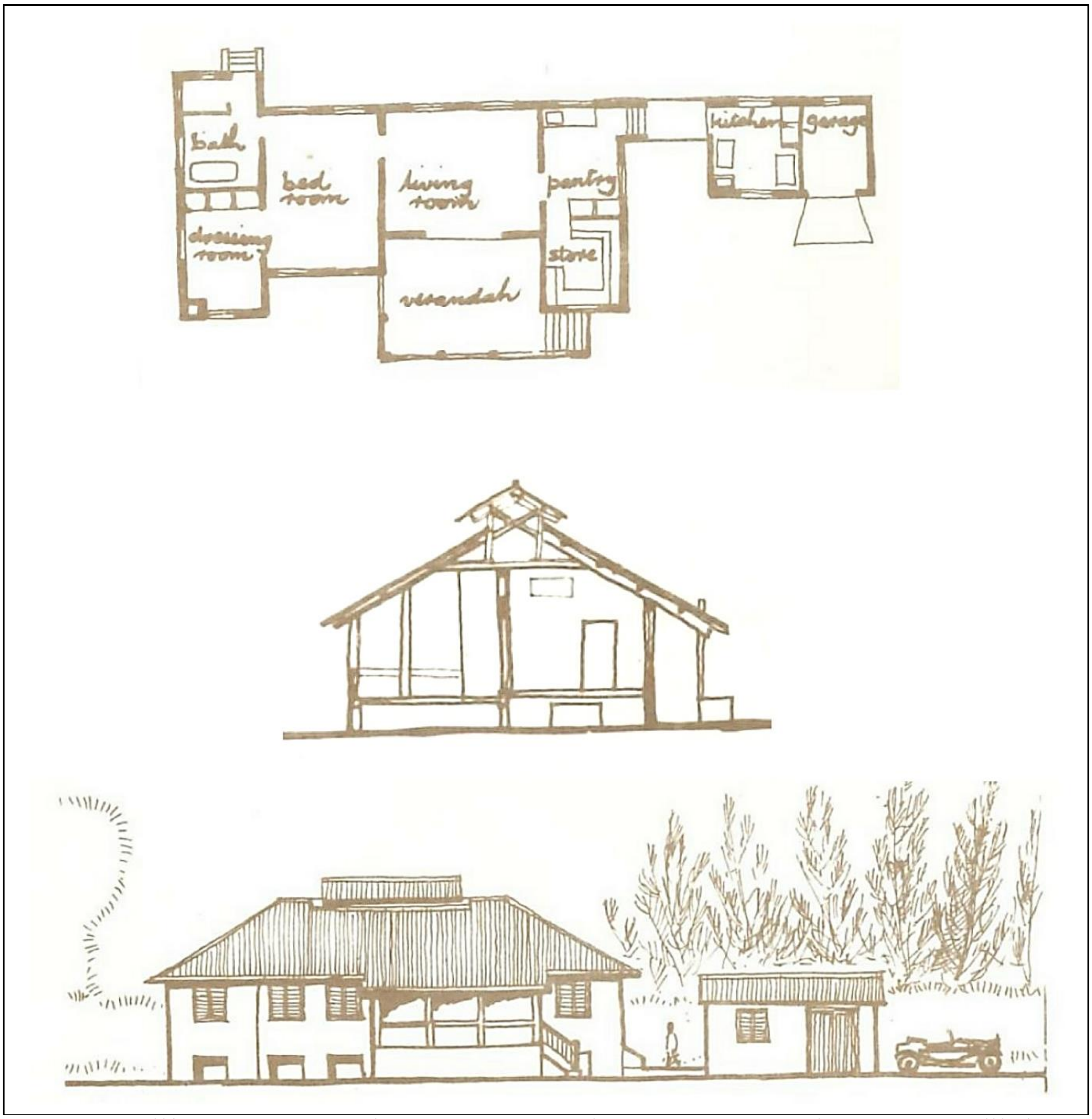


Figure 4.41 1925 PWD bungalow type T17A – notice stilted building frame; source: Akinsemoyin & Vaughan-Richards (1977).

The PWD residencies (ranging from multi-storey villas to bungalows) were built in areas called European Reservations which were exclusive to European/British officials (Mabogunje, 1962; King, 1984). The Reservations were designed according to the specifications in the Governor-General Lord Frederick Lugard's 1917 Townships Ordinance (King, 1984; Chokor, 1993). The 1917 Ordinance enforced the mandatory acquisition of Nigerian land for public reasons and to improve the Crown lands. The Reservations featured low-density housing with garden lay-outs. As such, each residence was built in an expansive plot with lawns, gardens, and recreational sections (tennis court, golf course) (see Figure 4.43). A plot was 91m long and 64m to 91m wide. It had a defined boundary made of a hedge, mud wall or any tangible fence. The compounds were landscaped and kept clean and bare by prisoner workers.

Figure 4.42 The second Government House in Lagos; source: The National Archives UK, CO 1069-78-9 “Nigeria” undated.

Servant accommodation and stables were positioned at the rear, by a backline and sanitary lane (King, 1984). Thus, the PWD initiated the creation of official colonial government residences. At the pinnacle of official colonial housing was the Government House as it reflected the colonial government’s seat of power (Home, 1997). The Government House was the residence of the Governor-General of a British colony (Ibid). In 1914, the Northern and southern Protectorates of Nigeria were amalgamated, and Lagos became the administrative capital (Bigon, 2006). Additionally, Lagos was termed a First-Class Township in Nigeria under the 1917 Township Ordinance (Ibid). Therefore, due to the city’s colonial relevance, a Government House was situated in Lagos. The relevance of the Government House in this era may be compared to that of the indigenous Yoruba palace in the traditional era. Akinsemoyin & Vaughan-Richards (1977) say there have been three Government Houses built in Lagos (Figure 4.42 shows the second Government House). The third and final version was redesigned in 1889 by the colonial surveyor general F. Anderson (Salami, 2016). Salami (2016) provides a description of the redesigned Lagos Government House. Constructed in 1894, the building had an ‘H’ shaped floor plan, five staircases and three floors (see Figure 4.44). The ground floor was used mainly for receiving guests and accommodating staff while the upper floor was for the governor’s administrative and domestic use. The rectangular, horizontal mid-section comprised of a central anterior hall with a billiard room on the right and a palaver hall on the left. The major staircase was constructed in the central hall and led up to the other floors.

Figure 4.43 The final Government House, Lagos built in 1894; source: The National Archives UK, CO 1069/65 “Nigeria” 1923.

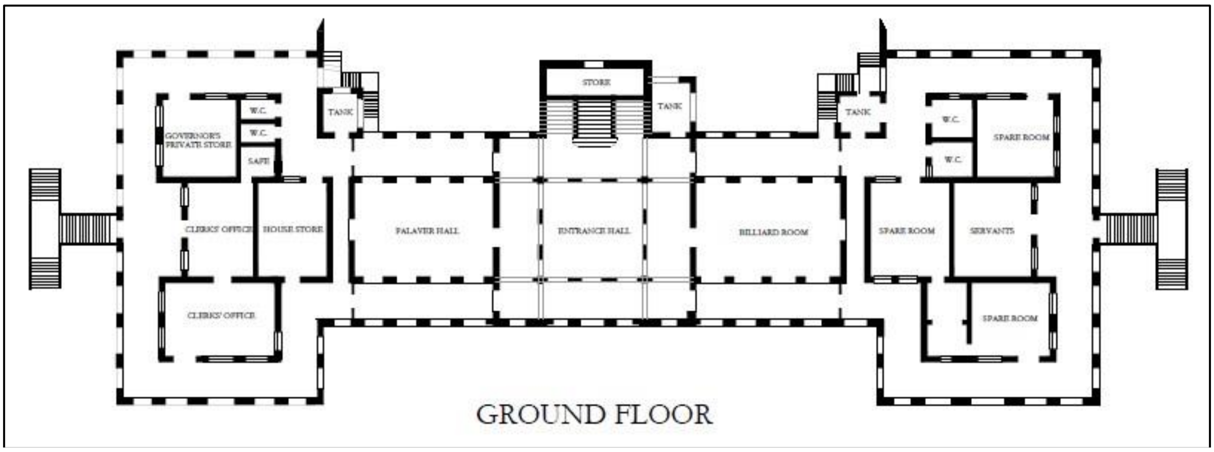


Figure 4.44 Ground floor plan of Government House as designed in 1889; source: Salami (2016, p.201).

The anterior, palaver and billiard halls were the welcoming areas before the official spaces. Four bedrooms made up the east block; two were used by servants and the other two served as guest rooms. The west block seemed to be the main administrative block, with two clerks’ offices, stores, a vault and lavatories. Verandas ran around the perimeter of the building’s functional areas. Two staircases linked the rear verandas of the east and west blocks to tanks on the roof level.

The Government House was built within an expansive site as typical of the European Reservations (see Figure 4.43). However, its surroundings and views were attractive as the site was situated not far from the water front. The lawns were landscaped and provided areas for recreational activities such as tennis and golf. The building fabric of the house was typical of PWD construction. The walls were built of solid brick, windows were timber casement shutters and corrugated iron sheets covered the roof (see

Figure 4.45 The 1894 Government House, Lagos; source: The National Archives UK, CO 1069-80-44 “Nigeria” undated.

Figure 4.46 Inside the 1894 Government House, Lagos – notice timber shutter windows typical of PWD colonial house fabrics; source: The National Archives UK, CO 1069-80-44 “Egerton in G.H., Lagos - Nigeria” undated.

Figures 4.45 and 4.46). The Lagos Government House is presently known as State House Marina and has been modified from the original plan (Akinsemoyin & Vaughan-Richards, 1977).

The European Reservations were separated from the indigenous residential areas by large expanses of undeveloped land (Mabogunje, 1962). According to Drew (1947), the Europeans lived away from the indigenes to avoid contractible diseases. Furthermore, the British implemented an indirect rule system where traditional rulers were still allowed to exercise their authority in the indigenous areas (Chokor, 1993; Bigon, 2015). Therefore, while colonial development was evident around the indigenous areas, the latter were run on the original native systems and mostly maintained the traditional physical layout. Traditional compound and semi-traditional Afro-Brazilian houses populated the south-west Nigerian indigenous reservations. The indigenous districts were composed of the original compound house areas and their suburbs where Afro-Brazilian houses were built (Mabogunje, 1962). By this time (the 1920s and 1930s), the colonial government had been established. It created an economy largely based on commercial agriculture. The economic growth caused indigenous farmers and their workers better earnings. Furthermore, south-west Nigerian indigenes were exposed to western education and government employment (Mabogunje, 1962; Mabogunje, 1971; Chokor, 1993). However, the colonial government ensured that the highest position a Nigerian could occupy was the executive position of chief clerk (Lloyd, Mabogunje & Awe, 1967). Thus, housing within indigenous reservations exhibited changes due to the new colonial society and economy. Young male members of traditional Yoruba families were able to acquire independence from their parents after working for a few years (Mabogunje, 1962). They converted their rooms into detached houses after the death of the compound heads. The mud buildings (now with corrugated iron roofs) were transformed into structures with cement-plastered walls, better ventilation and electricity (Ibid; Akinsemoyin & Vaughan-Richards, 1977) (see Figure 4.48). Other times, some built from scratch on the available land within the spaces that they called theirs. These versions were built in cement blocks, in a bid to reflect the improved economic status.

Consequently, the original traditional compound house-form began to disintegrate. Mabogunje (1962) calls this phenomenon growth by fission where there was a "…*replacement of simple, large structures by more complex and more numerous smaller units*…" (p.60) (see Figure 4.47). Additionally, the fissional growth of the indigenous neighbourhoods was encouraged by the adoption of foreign religions such as Christianity and Islam (Ibid; Lloyd, Mabogunje & Awe, 1967). These religions stipulated that the man, his wife and children were the fundamental social unit of a civilised society. This was in direct contrast to the extended family basic social unit of the Yoruba. However, as these religions were accepted, independent male converts began setting up single room houses for themselves and immediate families within the compound. Mabogunje (1962) adds that the men built within the compound because the Yoruba did

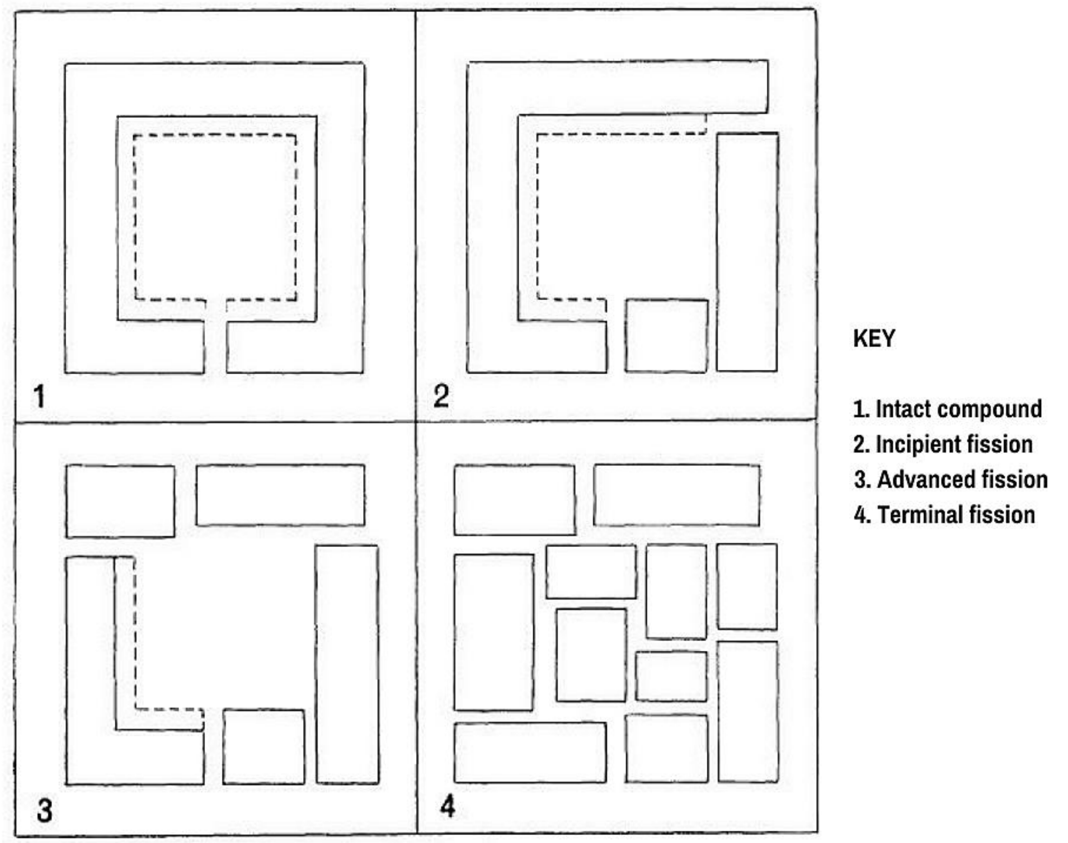


Figure 4.47 Representation of the compound disintegration process; source: adapted from Mabogunje (1962, p.60).

Figure 4.48 Aerial view of Molete residential area in Iwo, Osun State, showing 'modernised' compound houses at different stages of disintegration; source: Adenle (1969, p.24).

not demarcate land for sale but lived on land near their family compounds. Therefore, the independent males were inclined to build in the compounds and this caused the high density of houses in a constricted area. Furthermore, the inhabitants of the traditional neighbourhoods refused the implementation of the new town planning ordinances (Mabogunje, 1962; Mabogunje, 1971; Chokor, 1993) Consequently, the breakdown of the compound housing types into numerous single houses, increase in population density and deterioration in the quality of the area gradually continued.

The rooming/lodging/rest house became a popular type in the areas surrounding the compound house districts (Mabogunje, 1962; Osasona, 2007a; Okeyinka & Odetoye, 2010). The layout of the rooming house bears some semblance to the colonial barrack accommodation previously described (Home, 1997). The first variant of the rooming house-type was built to accommodate young, unmarried clerks working in the new business and administration sectors (Lloyd, Mabogunje & Awe, 1967). Migrants from other parts of Nigeria, seeking opportunities in the thriving south-west Nigerian colonial cities such as Ibadan and Lagos, occupied these houses as well. The migrants usually owned the houses in which they lived as they obtained land from the town's indigenes (Lloyd, Mabogunje & Awe, 1967; Chokor, 2007). The colonial town planning policies were implemented in these areas; as such the quality of planning and construction was higher than in the compound house districts (Chokor, 1993). The rooming houses were mostly one-storey, contained single rooms and were built in the Brazilian style. Typically, the rooming house consisted of a row of 10-12 rooms (3.0m by 3.7m by 2.4m each). The rooms were arranged in linear form on both sides of a central access corridor (5-6 rooms on each side), with a maximum width range of 1.8m to 2.4m (see Figure 4.49). The central corridor had an anterior entrance leading into the street and a posterior one leading into a backyard (Mabogunje, 1962). A single man rented one room and if he married he rented 2-3 rooms on a row.

This spatial morphology earned the type the well-known colloquial name 'face-me-I-face-you' (Yetunderonke, 2015). The rooms were usually multi-functional and multi-habited, where bedrooms would function as sleeping areas at night, a living and dining room at other times. A shared kitchen, bathroom and pit latrines were provided outside the house but within the compound (Mabogunje, 1962). The structure was built of cement blocks with corrugated-iron roofing; windows were made of timber (sometimes with glass panes) and were the side-hung casement type (see Figure 4.50). However, older versions were built of brick (Lloyd, Mabogunje & Awe, 1967). Overcrowding was common in the indigenous rooming house; extra occupants readily turned the central access corridor into a kitchen and laundry space. The owners of these rooming houses allowed high numbers of occupants because the rent was a source of income (Ibid). Therefore, indigenous residential areas in colonial south-west

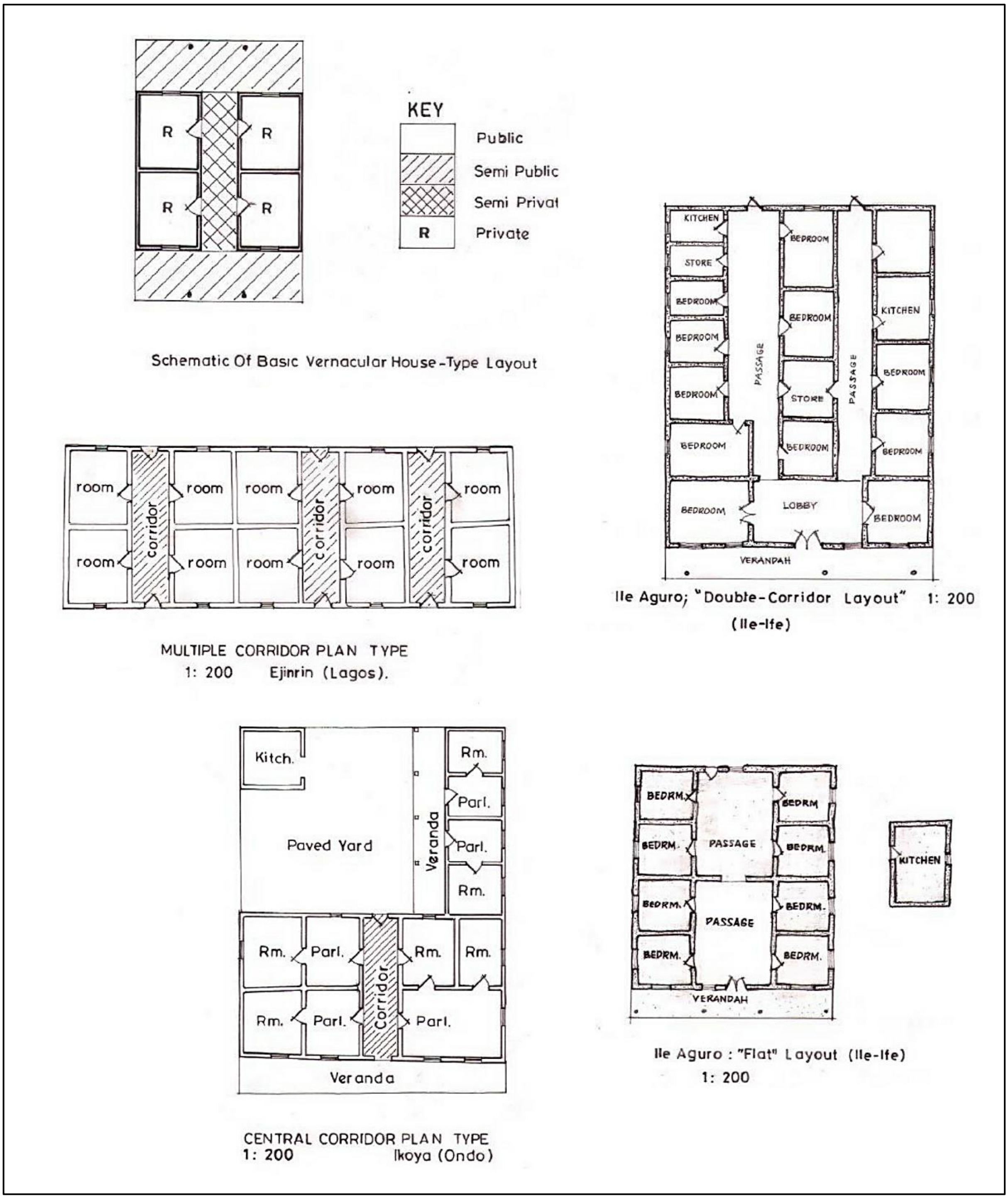


Figure 4.49 Different variants of the rooming house floor plan across south-Nigeria; source: Osasona (2007a, pp.12-16).

Nigerian towns were densely populated. The common pattern was that the traditional compound houses were occupied by the town's indigenes while the migrants from other Yoruba towns occupied Afro-Brazilian rooming houses. The disintegration of the compound house into single houses tightly packed together and the overcrowded numerous rooming houses caused the high housing and population density of indigenous neighbourhoods. Thus, a common feature of many colonial Yoruba towns was the sharp difference between the high-density indigenous districts and low-density European Reservations

Figure 4.50 Different variants of the rooming house, showing similar construction – cement block walls, corrugated iron roofing and timber casement windows, across south-Nigeria; source: Adeokun, Ekhaese & Isaacs-Sodeye (2013, p.4) – top image and Osasona (2007a, p.10) – bottom image.

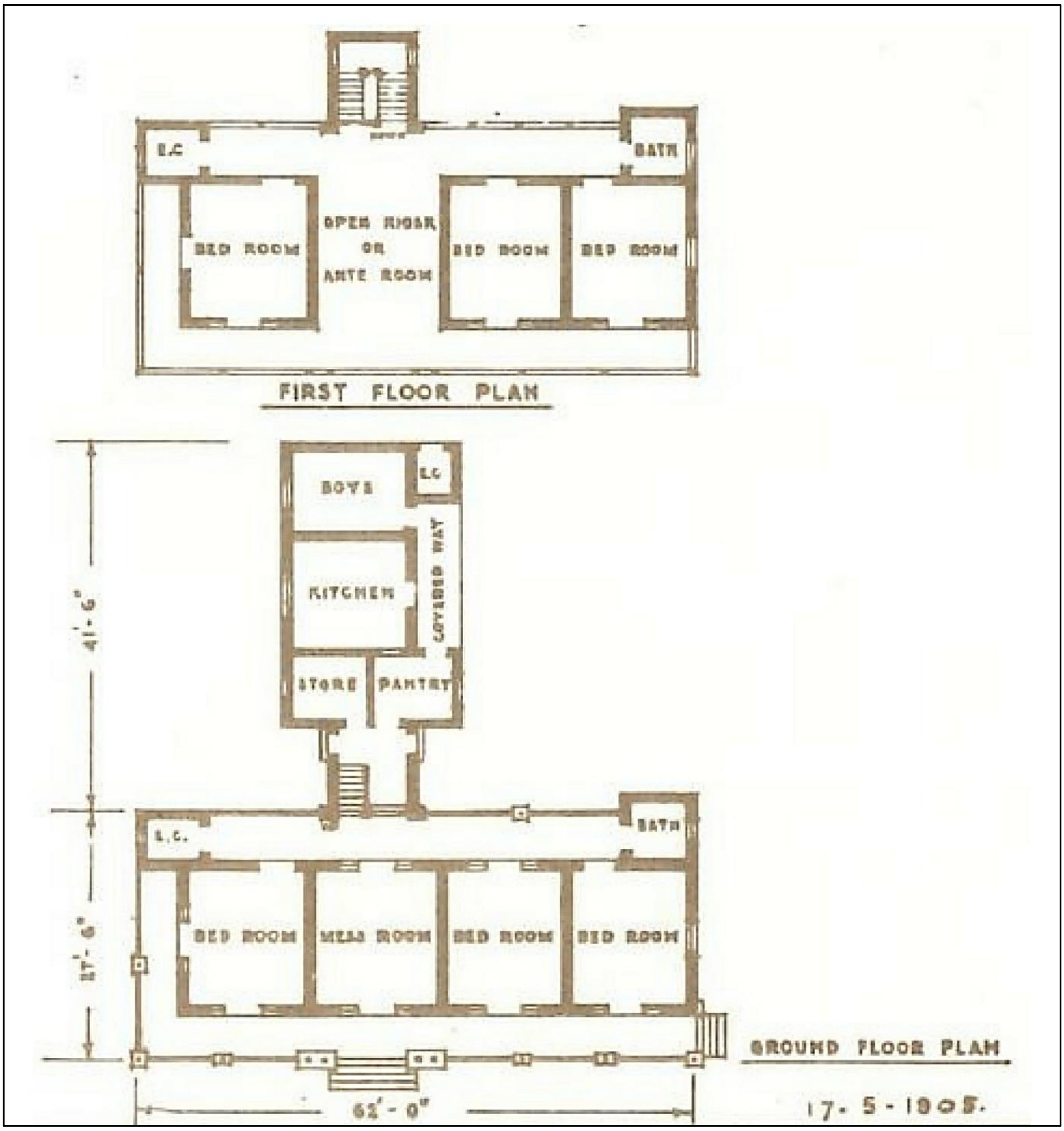


Figure 4.51 An example of the PWD rest house floor plan; source: Akinsemoyin & Vaughan-Richards (1977).

(Lloyd, Mabogunje & Awe, 1967). The breakout of fatal epidemics were said to originate in the indigenous districts because of the high population density (Mabogunje, 1962, 1971; Ibid).

Interestingly, some PWD plans were similar to the layout of the rooming house (Akinsemoyin & Vaughan-Richards, 1977). The PWD rooming house was referred to as a 'rest house' or 'guest house'. The PWD rest houses had their rooms on one side of the veranda passage (see Figure 4.51). Additionally, the kitchen and bathroom facilities were within the building. The PWD rest houses were of different grades; the higher grades served colonial officers while the lower grade served colonial workers (Ibid; Lloyd, Mabogunje & Awe, 1967). Examples include: the Governor's rest house in Ibadan, a first class rest house

Figure 4.52 The Governor's rest house, at Ibadan; source: The National Archives UK, CO 1069-64-27 "Governor's rest house Ibadan - Nigeria" undated.

Figure 4.53 The 1930 Railway rest house at Abeokuta, showing timber framed walls, iron roofing and timber shuttered windows; source: Salami (2016, p.239).

(see Figure 4.52) and the rest house for six men in Lagos, a second class rest house. The construction of these official rest houses showed classic PWD materials: timber and brick frames raised on stilts with corrugated iron roofing and timber casements shutters (see Figure 4.53).

In the late 1930s, 1940s and early 1950s, the late colonial period brought further changes to the south-west Nigerian housing landscape (Chokor, 1993). In 1946, the British Colonial Government established the Town Planning Ordinance for the physical development of Nigeria (Drew; 1947; Ibid). This was different from Lord Lugard's 1917 Ordinance. Additionally, the colonial government began to establish educational institutions where indigenes were trained (Jackson & Holland, 2014). The new drive for town planning and education created a demand for the development of new architecture and social amenities. Urban reform groups such as the Ibadan Progressive Union advocated for amenities such as roads, pipe-borne water and electricity (Livsey, 2014). Primary and secondary schools, teacher-training colleges, universities, hospitals, religious buildings were created (Vagale & Adekoya, 1974). As indigenes became educated, they were able to work in government sectors: health, education and administration. Thus, the transition to independence commenced in this period, specifically in the late 1940s and early 1950s (Mabogunje, 1962; Lloyd, Mabogunje & Awe, 1967; Akinsemoyin & Vaughan-Richards, 1977; Chokor, 1993). The south-west Nigerian region experienced tremendous economic growth and Nigerians from other parts of the country as well as non-Nigerians (Ghanaians, Sierra Leoneans, among others) began migrating to the major cities of Lagos and Ibadan (Lloyd, Mabogunje & Awe, 1967; Vagale & Adekoya, 1974). Lagos had been the administrative capital since 1914 and Ibadan had grown into a major West African metropolis (Vagale & Adekoya, 1974). The south-west Nigerian socio-economic strata evolved but generally Europeans occupied the higher levels (upper to upper-middle class) while most Nigerians occupied the lower levels (lower-middle class to lower class). However, the increasing population of low-income Nigerians in the major south-west cities led to the development of informal settlements.

According to Immerwahr (2007), the mid-late colonial informal settlements were houses of unplanned neighbourhoods built and occupied by Yoruba and non-Yoruba migrants on illegally obtained land on the outskirts of the planned indigenous areas. These migrants were young people who had moved from the rural villages to the big cities in search of employment (Akanle & Adejare, 2017). Those who had unsuccessful pursuits created these informal settlements. The traditional neighbourhoods with deteriorated compound housing had grown to be highly populated and were termed informal settlements as well (Fourchard, 2003) (see Figure 4.54). Aboutorabi (1985) describes the physical layout of these settlements as 'chaotic' because both areas did not show the order of colonial town planning. These became a common development not just in Lagos but in different south-west Nigerian cities. The informal houses were clustered together and without modern amenities such as electricity and pipe-borne water (Fourchard, 2003). The structure of the informal house was decrepit as its low-income owner or occupant could not afford standard construction. Immerwahr (2007) states that the informal houses did not have a style or typology. Nevertheless, he (Ibid) classed most of the layouts as based on that of the Afro-Brazilian-style bungalows. This seems logical as the informal houses were usually single rooms sharing walls or closely linked by narrow passageways sometimes covered and other times uncovered (Aboutorabi, 1985). Occasionally, a group of rooms (up to six in number) formed a family house.

Still the family houses were positioned so close to one another with no real definition among them. As such, these communities appeared like a big 'house' where the individual structures were constituent

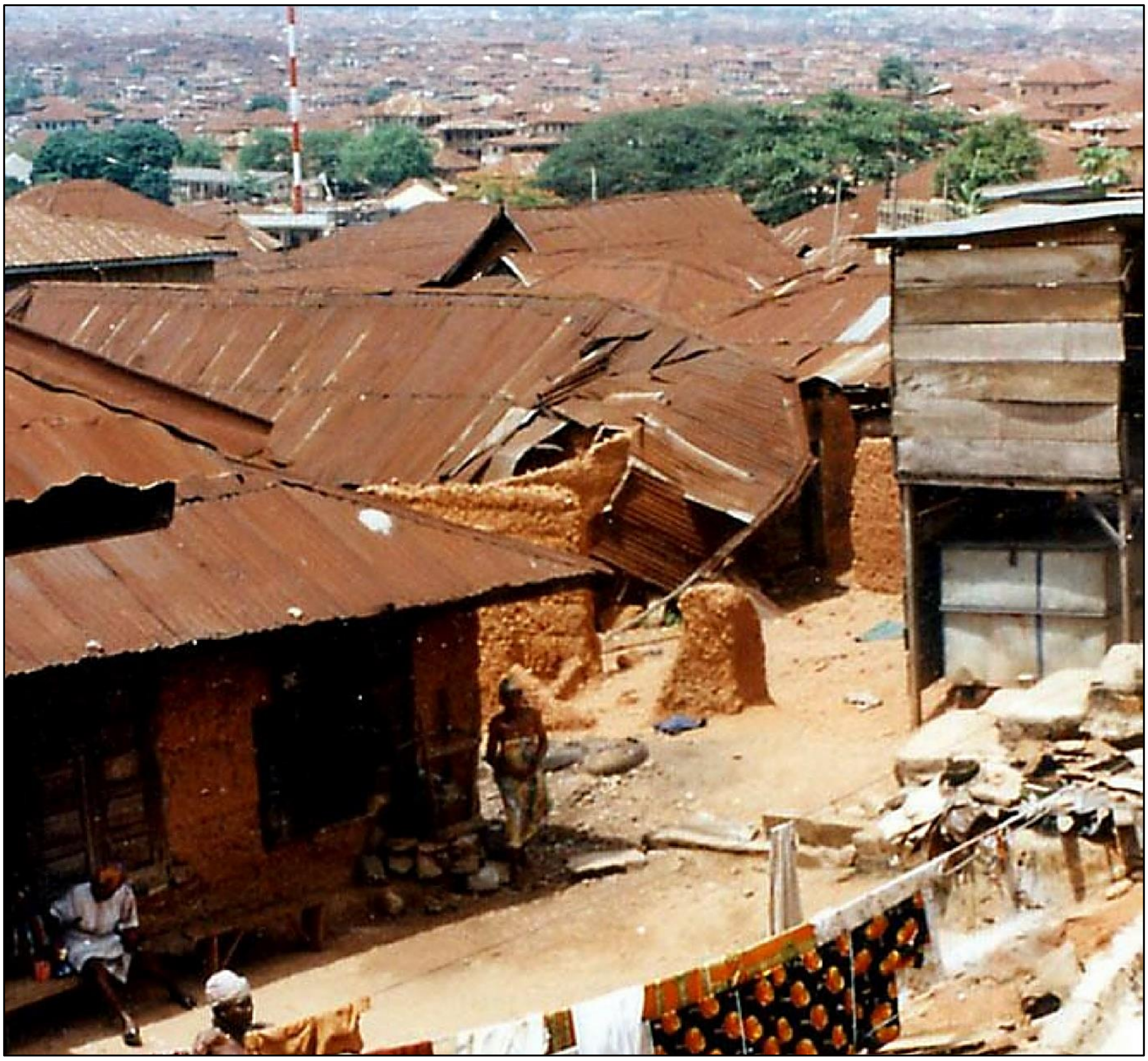


Figure 4.54 The disintegrated compound house types in Bere, Ibadan – notice the mud walls and corrugated iron roofing which constitute the first type of informal settlement envelope; source: Fourchard (2003, p.10).

spaces (Ibid). The overcrowding and high population density within the informal settlement went along with the strong social ties amongst its residents (Ibid; Fourchard, 2003). These ties facilitated the socio-economy the residents could only afford within their community. Informal housing was erected using cheap and locally available materials. Common building envelopes included type 1: mud/cement block walls (occasionally plastered in cement), timber roof trusses covered in corrugated iron sheets (see figure 4.54); type 2: timber walls (made of wooden planks or bamboo) and roof covered in corrugated iron sheets or thatch (see Figure 4.55); type 3: shacks of corrugated iron walls and roofs (see Figure 4.57) (Aboutorabi, 1985; Agbola & Agunbiade, 2009; Daniel, Wapwera, Akande, Musa & Aliyu, 2015). In the riverine areas such as Makoko informal settlement, timber framed bungalows with corrugated iron roofing or raffia palm thatch were built on stilts (Simon, Adegoke & Adewale, 2013; Daniel et al, 2015). Apart from the dilapidated appearance of these structures, bad hygiene was a standard characteristic and fatal

Figure 4.55 Stilted waterfront informal settlements in Makoko, Lagos – notice the timber/bamboo framed walls and corrugated iron roofing which constitute the second type of informal settlement envelope; source: Etomi (2012) – first image and Etomi (2011) – second and third images [used with permission].

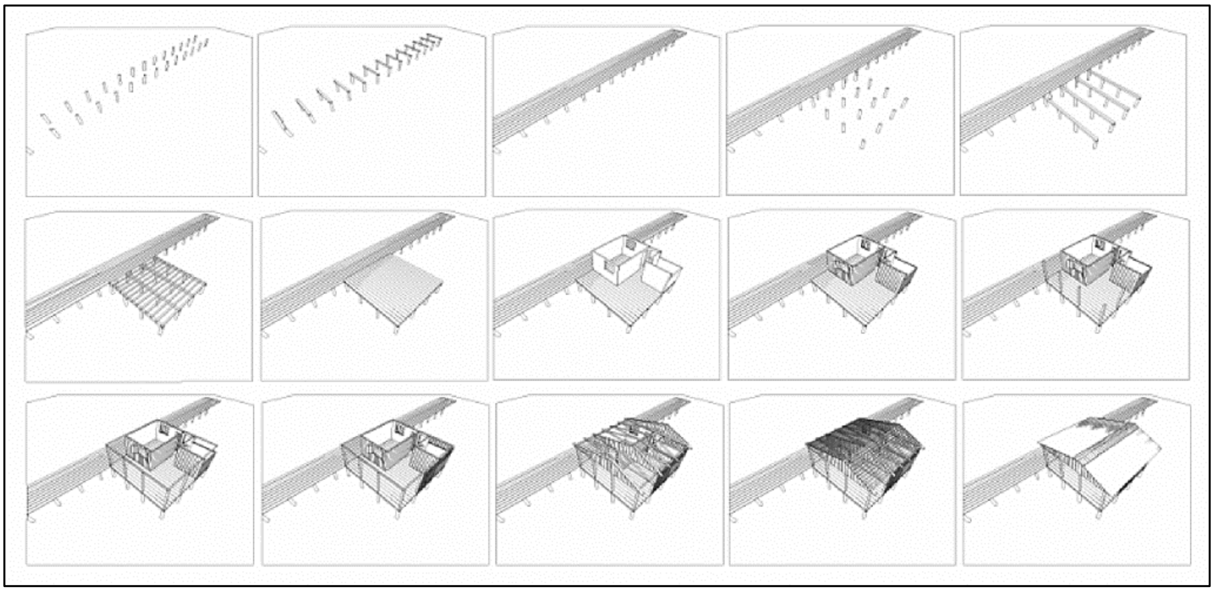


Figure 4.56 Construction sequence of stilted waterfront informal settlements in Makoko, Lagos; source: Etomi (2011).

Figure 4.57 Corrugated iron shacks in Ogudu, Lagos; source: Agbola & Agunbiade (2009, p.95).

epidemics originated in these areas as well as in the highly populated indigenous districts.

In response to these health threats, urban planning institutions such as the Lagos Executive Development Board (LEDB) (now the Lagos State Development and Property Corporation - LSDPC) were tasked with the control of growing informal settlements (Akinsemoyin & Vaughan-Richards, 1977; Immerwahr, 2007; LSDPC, 2016). According to Bigon (2015), the LEDB had been founded in 1928 after the bubonic plague broke out in Lagos in 1924. Immerwahr (2007) adds that for thirty years after its establishment, the LEDB existed to protect Europeans for health risks (most of which were said to have originated in informal settlements and indigenous reservations), and to promote the city's economy. The LEDB became active in physical development after World War II (Ibid). It handled living conditions with regards to private development, informal settlement clearance and extensive public housing projects (Overseas Building

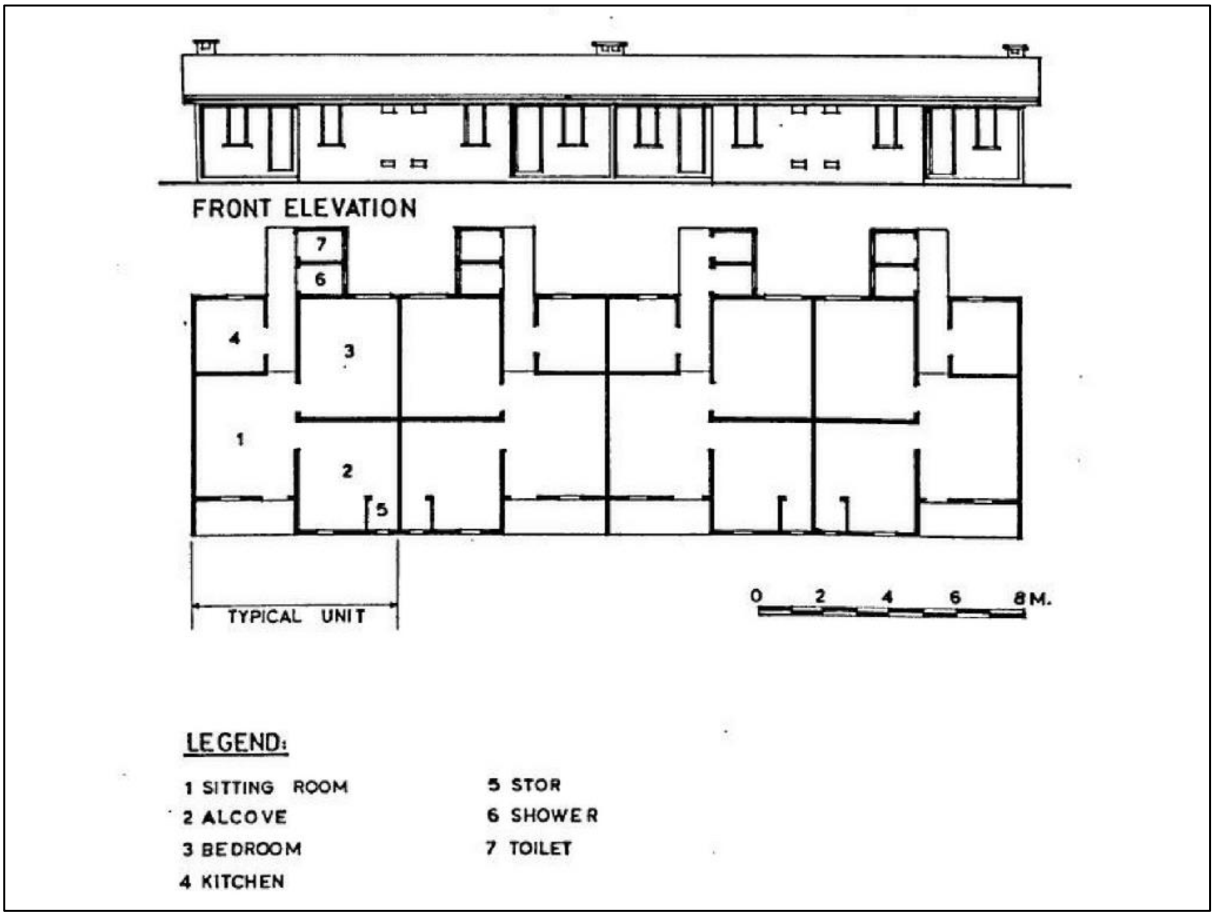


Figure 4.58 An example of LEDB terraced one-bedroom houses in Surulere; source: Aboutorabi (1985, p.194).

Figure 4.59 An example of LEDB terraced one-bedroom houses in Surulere; source: Marris (1961, p.153).

Notes, 1958; Akinsemoyin & Vaughan-Richards, 1977). The LEDB erected low-cost housing estates in Lagos (Surulere and Apapa); the houses were built to accommodate the people who had been moved from previous housing due to informal settlement clearance. The low-cost house types consisted of one-storey terrace houses, double-storey flats and single-room houses (Colonial Building Notes, 1961). The two-storey flats had two-three bedrooms, kitchen, bathroom and water closet. The one-storey terrace

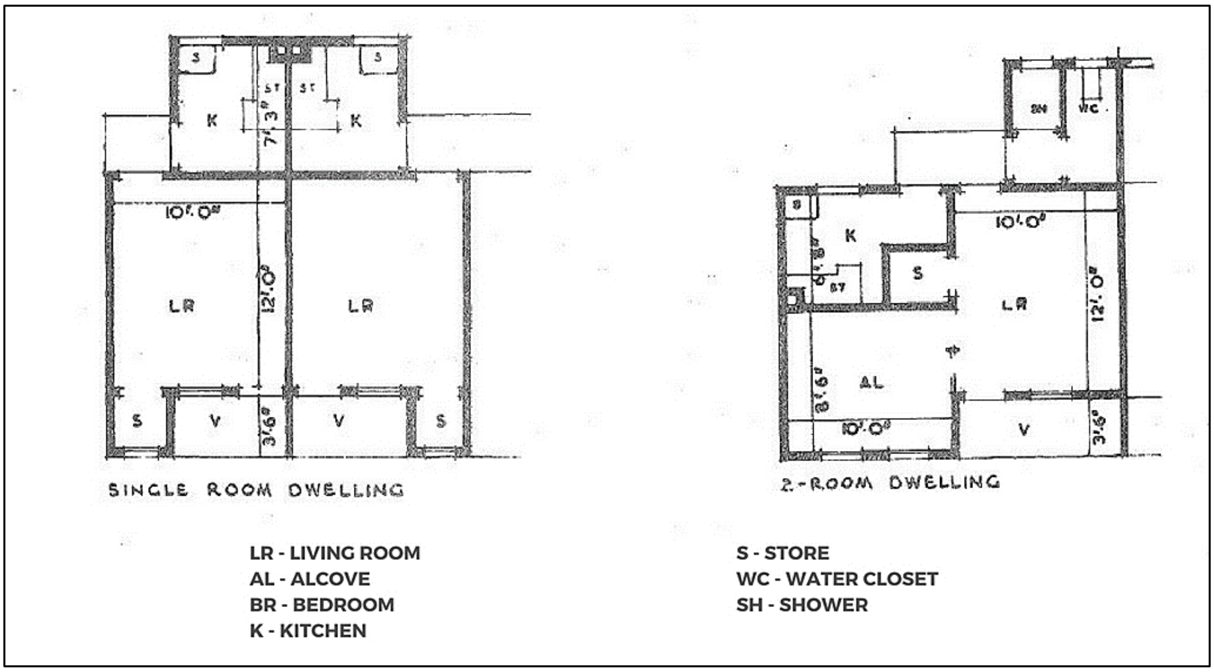


Figure 4.60 LEDB floor plans for single room and double room housing units; source: The Overseas Building Notes (1958, p.53/23).

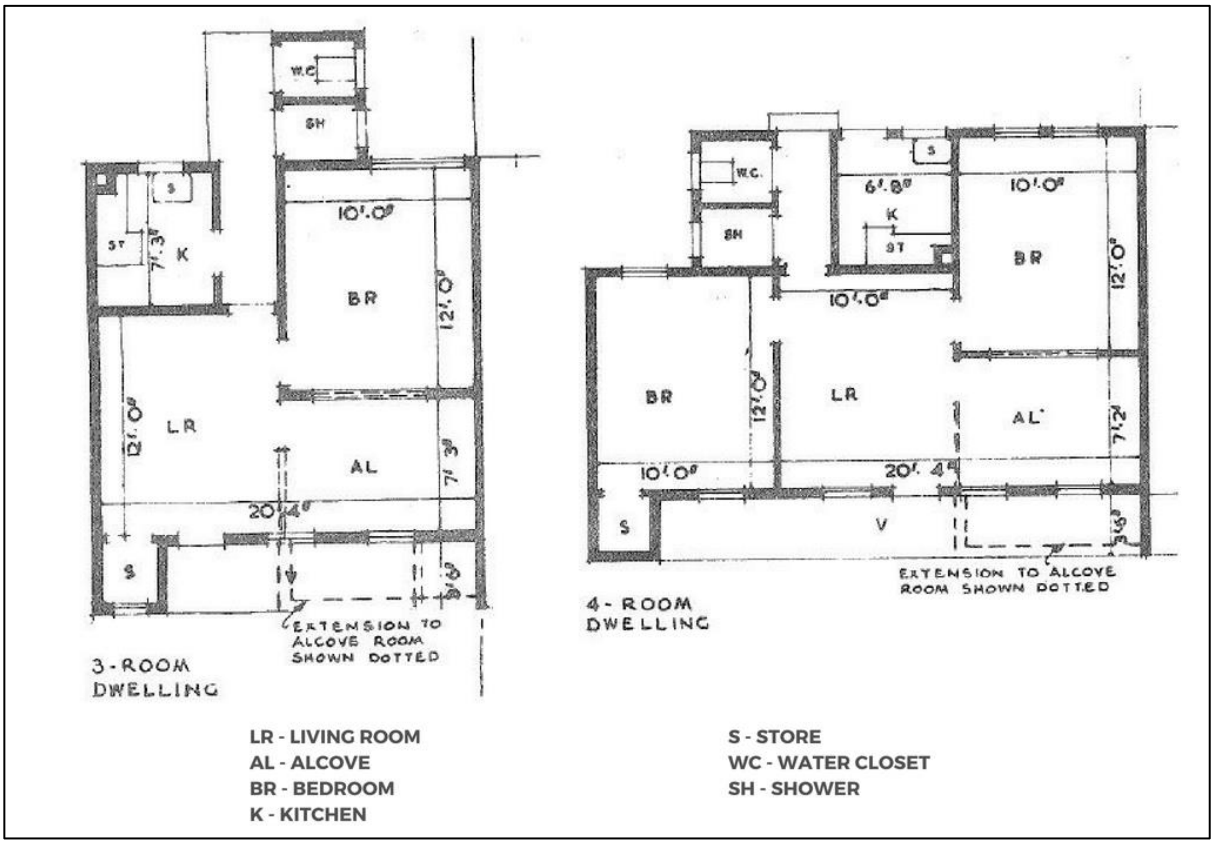


Figure 4.61 LEDB floor plans for three room and four room housing units; source: The Overseas Building Notes (1958, p.53/23).

houses had one to four rooms (usually for communal activities and sleeping), kitchen, shower and water closet (see Figures 4.58, 4.59 and 4.60 and 4.61). The single-room house had a self-serving kitchen; every half-dozen single-room house shared sanitary facilities. The typical bedroom of an LEDB low-cost house measured 3.7m by 3.0m (Overseas Building Notes, 1958). The houses were either rented to the low-income class at a subsidised rate and/or sold to the public to encourage the middle-class to own their houses (Ibid). The building envelopes of the LEDB houses seemed to demonstrate influences from the British Modern Movement which had gained prominence at the time of its establishment (Jackson & Holland, 2014). The Modern Movement (1918-1939) produced sturdy architectural forms with industrial products mainly concrete, steel and glass (Akinsemoyin & Vaughan-Richards, 1977). As such common LEDB envelopes showed cement block walls, cement floors with glass windows and corrugated iron sheets on timber frame (Aboutorabi, 1985). These low-cost housing schemes succeeded in some areas of Lagos; however, in other south-west Nigerian cities such as Ibadan, the residents of informal settlements refused to leave. Chokor (1993) says that they did not move because of unbroken attachments to family land, relatives and traditional socio-cultural systems.

On the other hand, the PWD built its type designs for government staff housing where the quality and type of housing was based on the occupant's salary and status (Salami, 2016). The types for the lower-income classes were easy to reproduce. For instance, the 1950 three-storey block of flats was a ubiquitous model used all over the region and an example of the public housing models which became popular at this time (Akinsemoyin & Vaughan-Richards, 1977; Home, 1997) (see Figure 4.62 and 4.63). The block of flats was alternatively called a chawl or tenement block (Home, 1997) and was designed to deal with the increasing demand for housing in the late colonial period. The apartment blocks possessed uncomplicated geometrical forms and were built with low ceilings, cement block walls, concrete flooring and corrugated iron roofing (Prucnal-Ogunsote, n.d.; Aboutorabi, 1985; Uduku, 2006). Windows were typically glass louvres with mosquito proofing. A standard flat had a sitting room, bedroom, kitchen, bathroom and laundry space (Immerwahr, 2007). A block was made up of several floors; each floor possessed a number of flats and a central stairway provided access to the apartments on each floor. Occasionally, a group of blocks would share a common courtyard space. Despite the popularisation of concrete and glass in this period, a few PWD designs displayed older construction such as the 1945 PWD type A3 T43 which had a unique floor plan and was built of timber frame under a corrugated iron roof (Akinsemoyin & Vaughan-Richards, 1977).

British architects saw the growth of late colonial south-west Nigeria as opportunity for practice. The prominent British architects involved in the physical development of south-west Nigeria were husband and wife Maxwell Fry and Jane Drew (Akinsemoyin & Vaughan-Richards, 1977). Fry and Drew had come

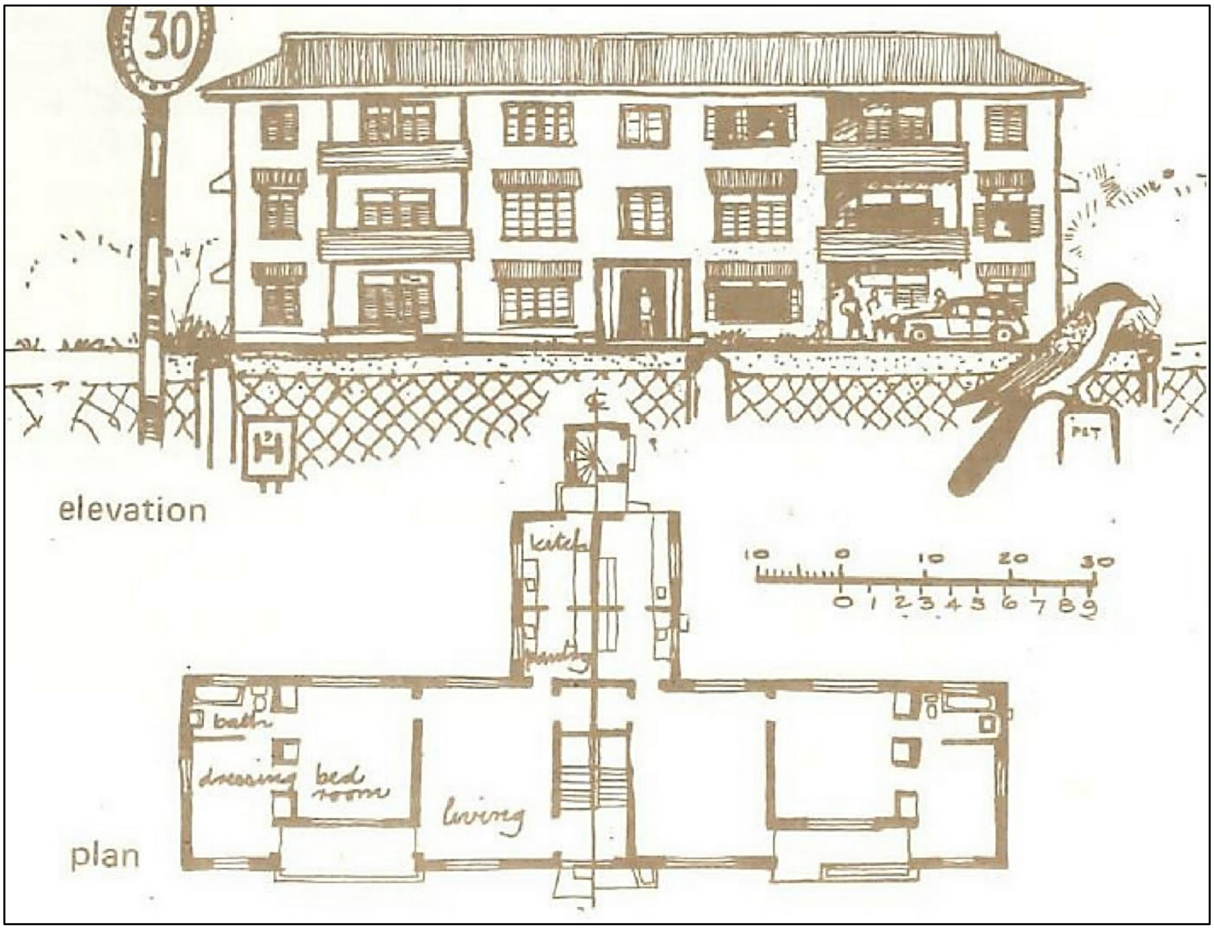


Figure 4.62 Floor plan and elevation for a typical 1950 block of flats; source: Akinsemoyin & Vaughan-Richards (1977).

Figure 4.63 Typical LEDB block of flats for public housing – notice solid cement block walls and glass louvred windows; source: LSDPC (2016).

to Nigeria when the Colonial Government appointed them as planning officers in West African colonies which included Sierra Leone, Ghana, Nigeria and Gambia (Ibid). They were leaders in the Modern Architecture movement and its principles influenced their work in the colonies. Fry and Drew were prominent figures (arguably the most prominent) in the landscape of modernism in West Africa. Their 1947 publication *Village Housing in the Tropics* contributed to their recognition as key characters in the development of tropical modernism in the mid-1900s (Jackson & Uduku, 2016). Jackson & Holland (2014) state that Jane Drew was very practical, able to offer architectural solutions in an era where resources were scarce. On the other hand, it appears that Fry was the designer of the duo, a machine which produced blueprints for appealing architecture (Ibid). His motivations were very artistic and concerned with the design details. In one of Fry's letters to Drew dated January 1946, Fry initially acknowledged Drew's stance that modern architecture limits the ability of the designer to experiment and express creativity. However, Fry later mentioned that the expressive modern designs of Le Corbusier changed his mind about Drew's said restriction of modern architecture. Therefore, their architecture was a laudable blend of practical solutions and aesthetics inspired by geometric modernist forms and local motifs. Fry and Drew's designs featured adaptive responses to the African climate such as sun-breakers and grilles which provided shading and ventilation. The patterns for the grilles followed African motifs (Jackson & Uduku, 2005). Furthermore, they utilised the traditional compound house layout for some of their housing projects (Jackson & Holland, 2014). Therefore, their structures exhibited a blend of geometric modernist forms and local motifs as well as climate-responsive features, which created the style tropical modernism.

Fry and Drew's tropical modernist architecture was based on three criteria which may be said to coincide with the present tenets of sustainable development (Fry & Drew, 1956; Thiele, 2013). These criteria and corresponding modern sustainability principles are:

1. the people and their needs – social sustainability (health, adaptability, lifestyle);
2. climate and its attendant ills - environmental sustainability (climate-responsiveness);
3. materials and means of building – economic sustainability (cost of building; availability of materials).

Their architecture fostered development and welfare causes in the colonies. They studied the lifestyle of the indigenes and identified the problems which were mostly related to hygiene. Their work was influenced by the designs of the Public Works Department; the PWD similarly considered climate-responsiveness and local construction (Jackson & Uduku, 2016). Jackson & Holland (2014) assert that they based most of their designs on already-existing colonial building codes including, the building guidelines of the PWD. However, they used the standard PWD housing guides to design more individual projects for their clients (Jackson & Holland, 2014). Their residential buildings in south-west Nigeria included staff housing and student dormitories for the missionary and modern schools they designed. A most notable example of their work in south-west Nigeria is the University of Ibadan. The West African Commission chose Ibadan as the site for the first University of West Africa (Ibid). As discussed earlier, the original site was the *Eleyele* barracks. However, Fry and Drew were commissioned to design the new campus on a new site: Oduduwa Road, northern outskirts of Ibadan (Soyinka, 1994; Livsey, 2014). This new campus became the University College Ibadan (UCI), established in 1948 and now known as the University of Ibadan (Mabogunje, 1971; Livsey, 2014).

The administrative, faculty and religious blocks were modern, painted structures with geometric and expressive forms, typical of Fry and Drew's tropical modernism (Livsey, 2014). There was attractive landscaping and well-kept lawns. The new campus accommodated an upper-class community of Nigerian lecturers who had trained abroad (Soyinka, 1994). There were residential sections as well as social clubs which sustained the highbrow academic community (Ibid). The student residences were built on a college plan where each student had a study bedroom, similar to the University of Oxford (Atkinson, Halliday, Olumuyiwa & Scott, 1963; Livsey, 2014). Each study bedroom was 3m wide, had its own balcony with decorative precast balustrades (Hitchins, 1978; Jackson & Holland, 2014). The student residences were designed to accommodate 200 students (Atkinson et al, 1963). Moreover, the students' halls of residence included lecturers' flats, with louvred windows and concrete screens (see Figures 4.64, 4.66, 4.67, 4.68, 4.69, 4.70, 4.71 and 4.72).

According to Hitchins (1978), the building envelope of the study bedroom consisted of structural concrete block walls 230mm thick and reinforced concrete floor slabs 100mm thick on average (see Figure 4.64). Casement glass windows admitted light and air (Jackson & Holland, 2014) (see Figure 4.65). The residential blocks were roofed with timber purlins covered in asbestos or aluminium. Formal dining halls, common rooms and courtyards with lawns were additional features (Livsey, 2014). The dining halls and common rooms were built with fabrics made of reinforced concrete beams and columns with concrete block wall panels (Hitchins, 1978). One of the dining halls was built with a 76mm thick reinforced concrete shell roof with 'Evode' water proofing which spanned 13m on a ceiling made of timber shutters (Ibid). The staff residential quarters included blocks of flats, compound or courtyard bungalows for African staff and bungalows for European staff (Jackson & Uduku, 2016). During the university's early years, most of the lecturers were foreigners and mostly British. However, the percentage of Nigerian lecturers slowly increased within a decade of the University's establishment (Livsey, 2017). The lecturers were given many privileges and desired modern housing like those of the Government Reservations (Ibid). This appears as a motivation for Fry and Drew's incorporation of PWD building guidelines into their designs.

Figure 4.64 Tedder student Hall of residence at the University College, Ibadan – notice concrete screen wall; source: Jackson & Holland (2014, p.265).

Figure 4.65 Exterior detail of Mellanby student accommodation block – notice reinforced concrete frame and casement windows; source: courtesy of RIBA Archives.

Figure 4.66 Exterior view of Mellanby Hall from inside Tedder Hall; source: courtesy of RIBA Archives.

The staff houses were classified into two categories: the African Masters' House and the European Masters' House (Jackson & Holland, 2014). The article on European Houses in West Africa, from the 1952 *Buildings* journal describes the design of three European house-types: 'H', 'K' and 'M' (See Figures 4.73 to 4.75). These types were sited using garden arrangements similar to the European Reservations, on the mild south-west slants of the hill facing the main University structures. They were oriented in the east-west direction to take advantage of the dominant south-west breeze. Moreover, the houses were designed with fixed timber louvre windows to allow continuous ventilation. However, there was a range of window types for the staff houses: side hung glass and top-hung casement windows, movable glass louvres in timber frames (which appear most popular among the types). The boys' quarters where servants lived were posited to the south of and separated from the houses by planting. Some houses shared one block of servants' quarters. Types 'H' and 'K' had two bedrooms while 'M' had three. All three

Figure 4.67 Exterior view of staff flats at Tedder Hall of Residence; source: courtesy of RIBA Archives.

Figure 4.68 Exterior view of staff accommodation at Mellanby Hall of Residence; source: courtesy of RIBA Archives.

Figure 4.69 Exterior view of staff housing with R.C. Chapel in background; source: courtesy of RIBA Archives.

Figure 4.70 Exterior view of African staff housing; source: courtesy of RIBA Archives.

Figure 4.71 Interior view of staff housing; source: courtesy of RIBA Archives.

Figure 4.72 Exterior view of courtyard to staff house; source: courtesy of RIBA Archives.

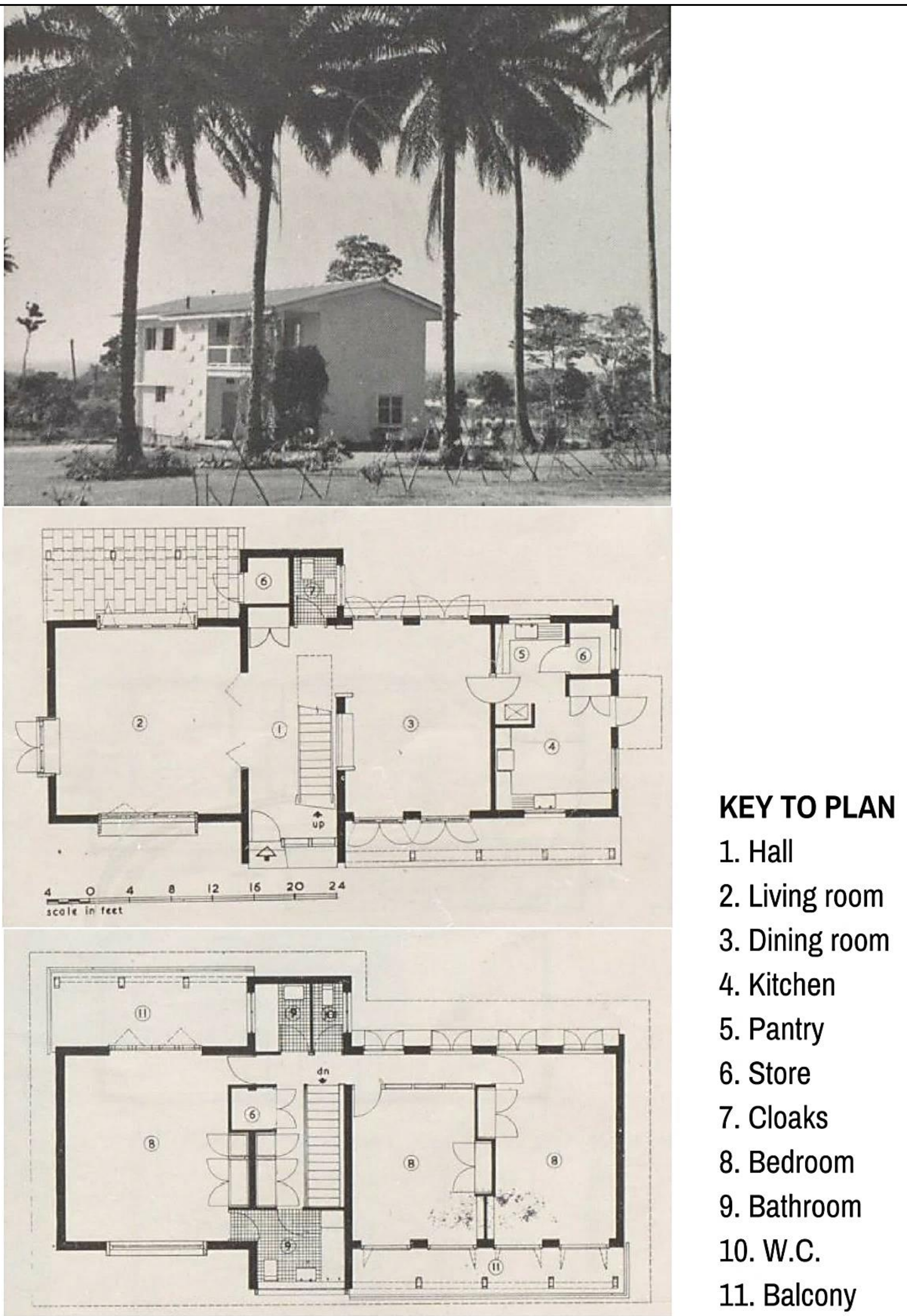


Figure 4.73 European staff residence at the University of Ibadan (Type 'M' house); source: Author Unknown (1952, p.303).

types were built with similar construction. The roofs were constructed with timber trusses, covered in asbestos cement Trafford tiles. The walls are composed of load-bearing concrete blocks made in situ and set within reinforced concrete beams and columns. The wall surfaces are rendered smooth, finished with lime or cement and paint. To add texture, some small areas were finished with stone. Contrarily, the African Masters' House was modelled on the traditional compound layout and were noticeably smaller than the European bungalows (Jackson & Holland, 2014). According to the 1952 *Buildings* journal, Type

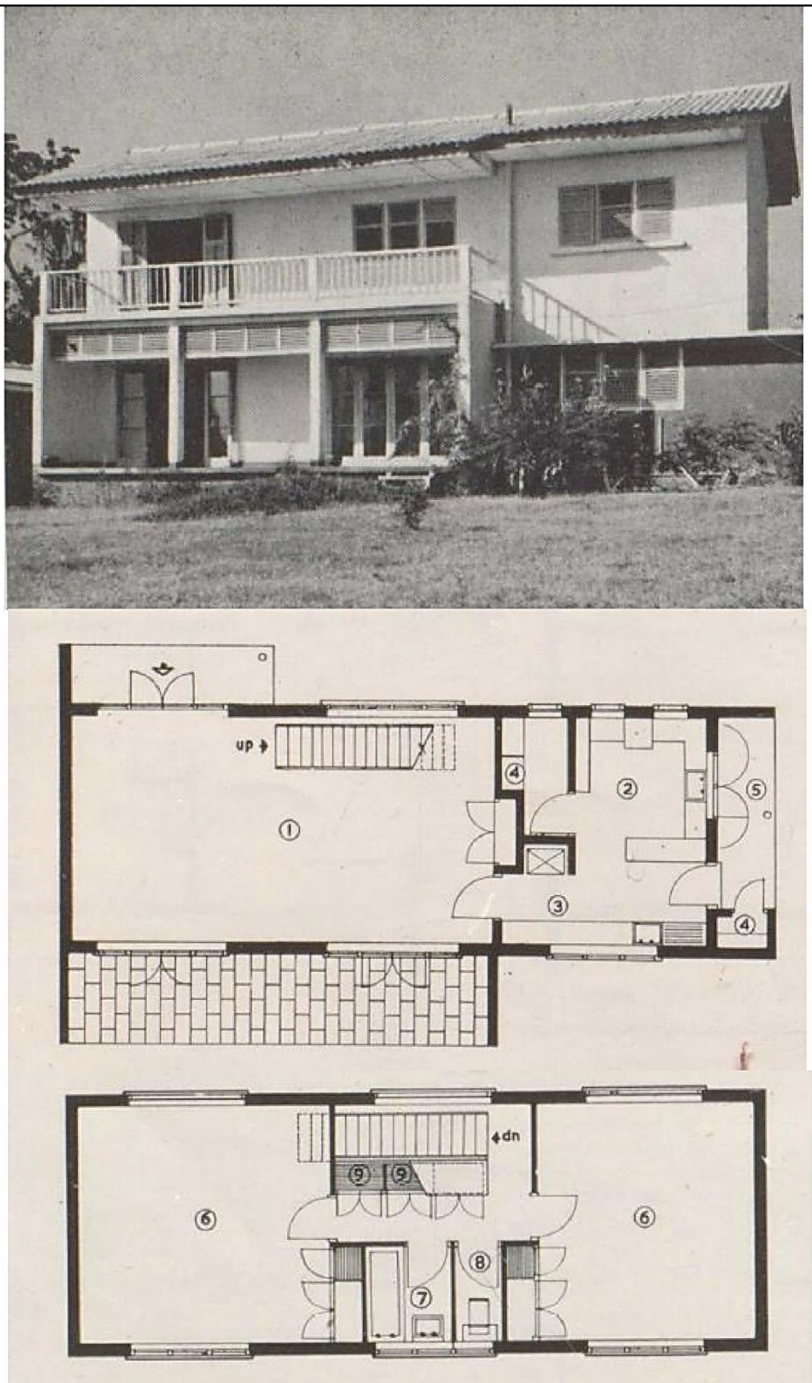


Figure 4.74 European staff residence at the University of Ibadan (Type 'K' house); source: Author Unknown (1952, p.304).

'C', among others, was designed for the African Staff Housing Area or 'African village', located north of the main campus (see Figure 4.76). Type 'C' was a bungalow with two bedrooms; it was built in pairs. The construction of type C was similar the European types; however, the roof was mono-pitched and covered in 22-gauge, ribbed aluminium sheets on insulation.

Towards independence in 1960 and the end of the late colonial era, the quality of the student and staff residences dropped due to the criticism that they were too expensive to maintain (Livsey, 2014). After 1960, the administrators of the university thought that the student residences were too expensive and

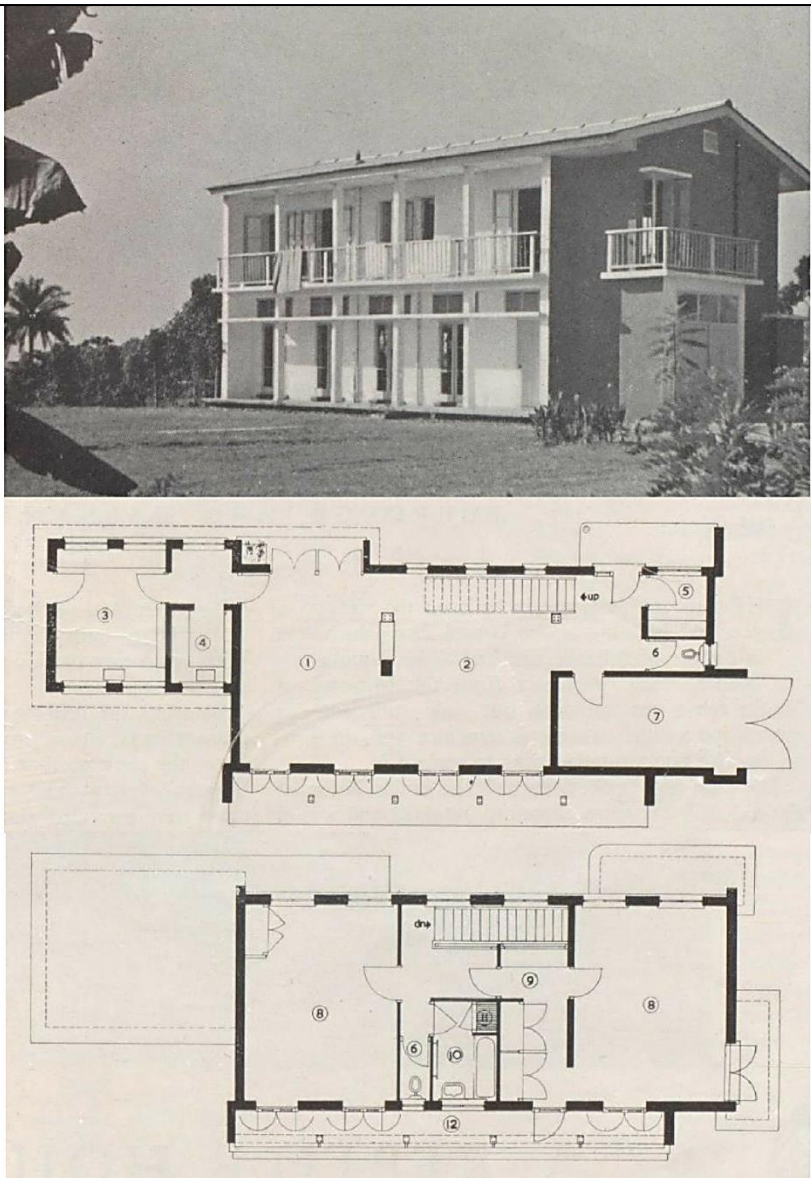


Figure 4.75 European staff residence at the University of Ibadan (Type 'H' house); source: Author Unknown (1952, p.305).

luxurious as the University was run on British grants and limited Nigerian revenue (Ibid). By this time, other tropical modernist architects and architectural firms, such as the Architects Co-Partnership, Godwin & Hopwood, Nickson & Borys and Design Group were active in the south-west Nigerian region (Fry and Drew, 1964; Akinsemoyin & Vaughan-Richards, 1977; Jackson & Uduku, 2016). Therefore, in 1959, Design Group architects in collaboration with structural engineers from Ove Arup & Partners produced designs for cheaper student accommodation the University of Ibadan (Atkinson et al, 1963). Simultaneously, the number of students per room increased in the original halls and non-resident students were admitted (Livsey, 2014). The gently-sloping site of the new residencies was located on the high ground of the University campus' south perimeter, towards the Awba stream (Atkinson et al, 1963) (Figure 4.77 shows the site plan of the new residential buildings). Atkinson et al (1963) provide detailed description of the new residences. The new scheme provided study bedrooms which catered to two students each

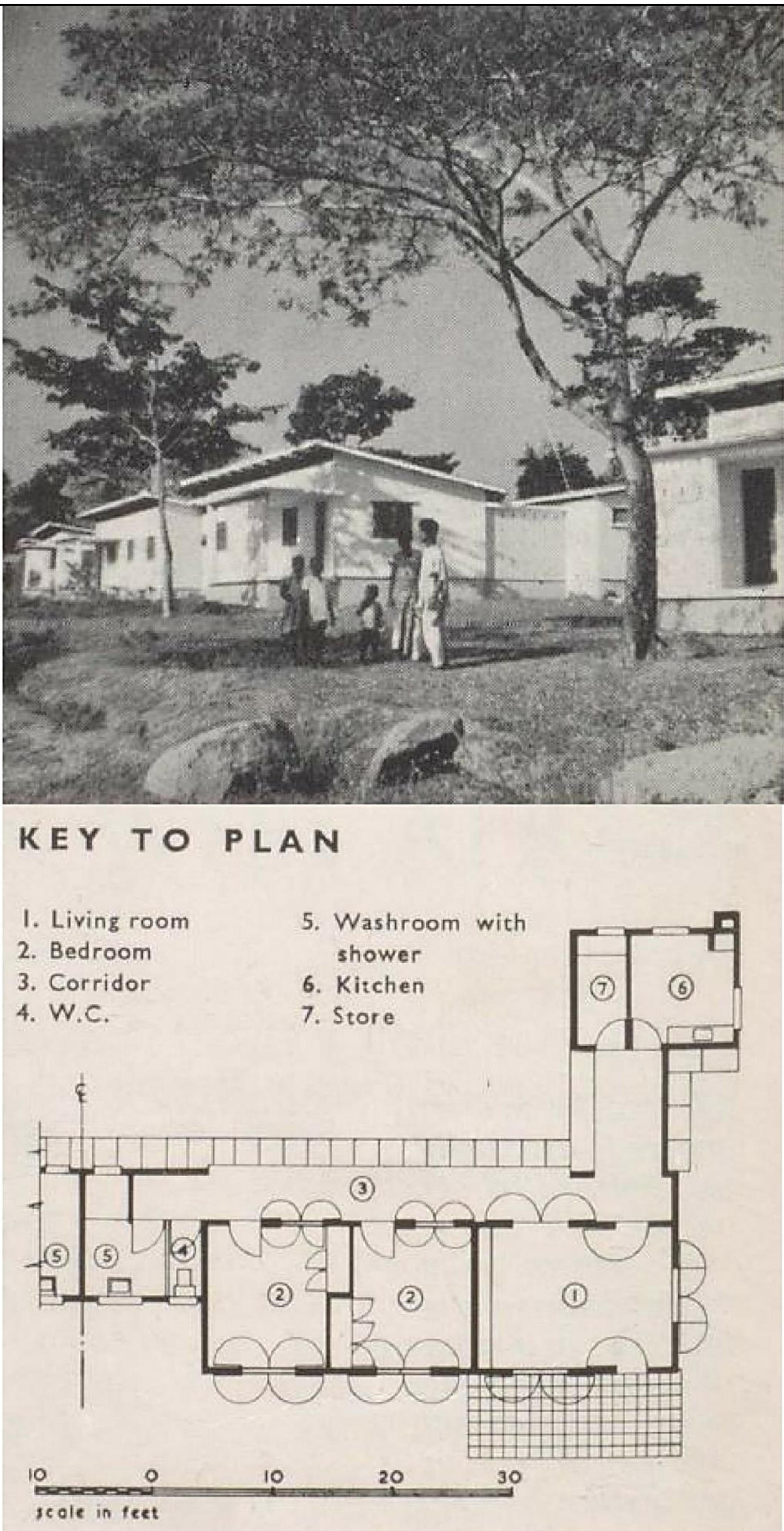


Figure 4.76 African staff residence at the University of Ibadan (Type 'C' house); source: Author Unknown (1952, p.304).

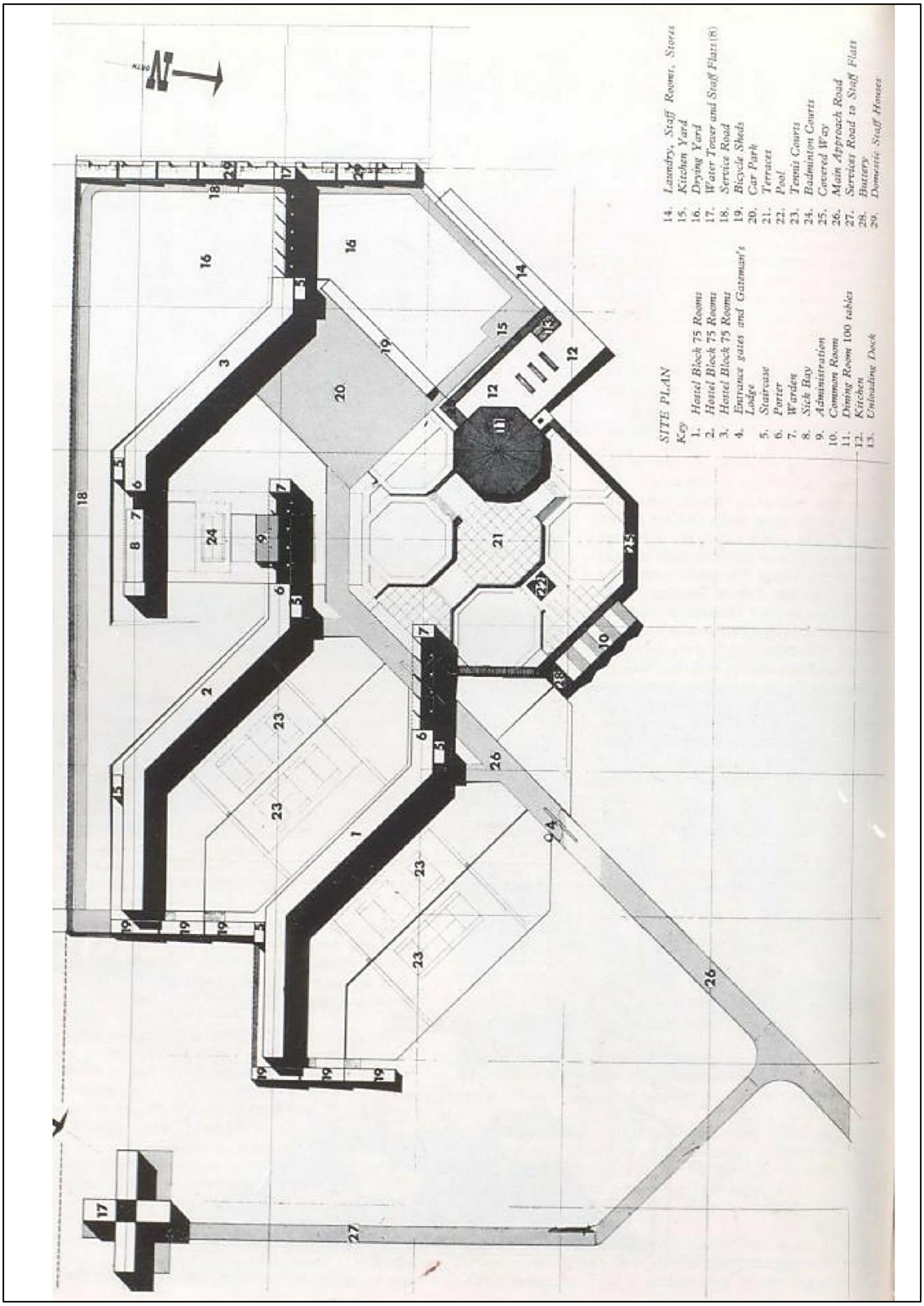


Figure 4.77 Site plan of new student residencies at the University of Ibadan, as designed by Design Group Architects; source: Atkinson et al (1963, p.103).

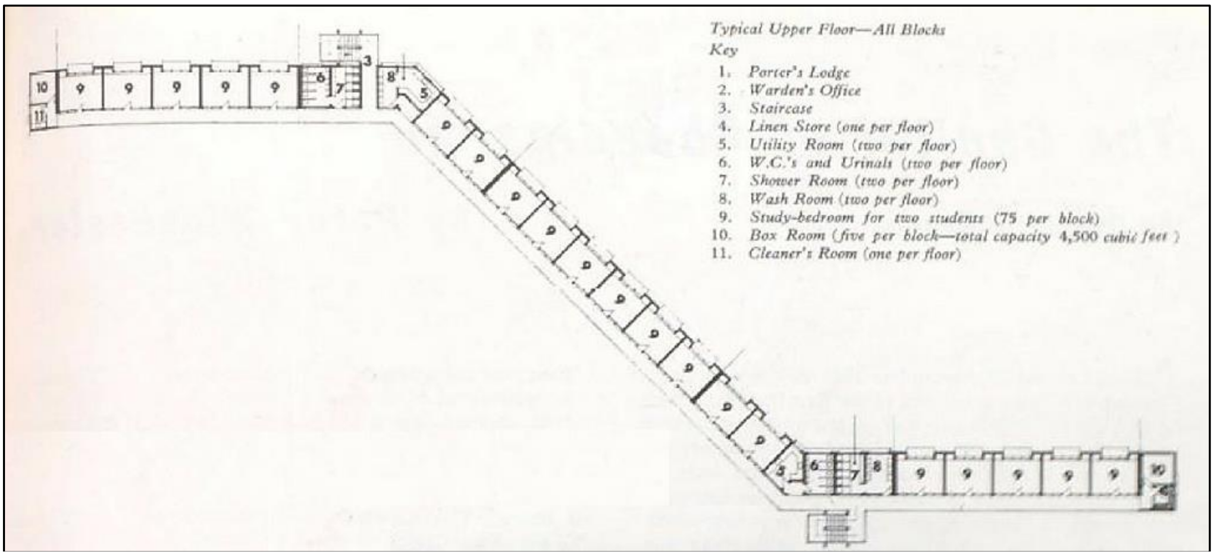


Figure 4.78 Upper floor plan of the new student residential blocks at the University of Ibadan, as designed by Design Group Architects; source: Atkinson et al (1963, p.104).

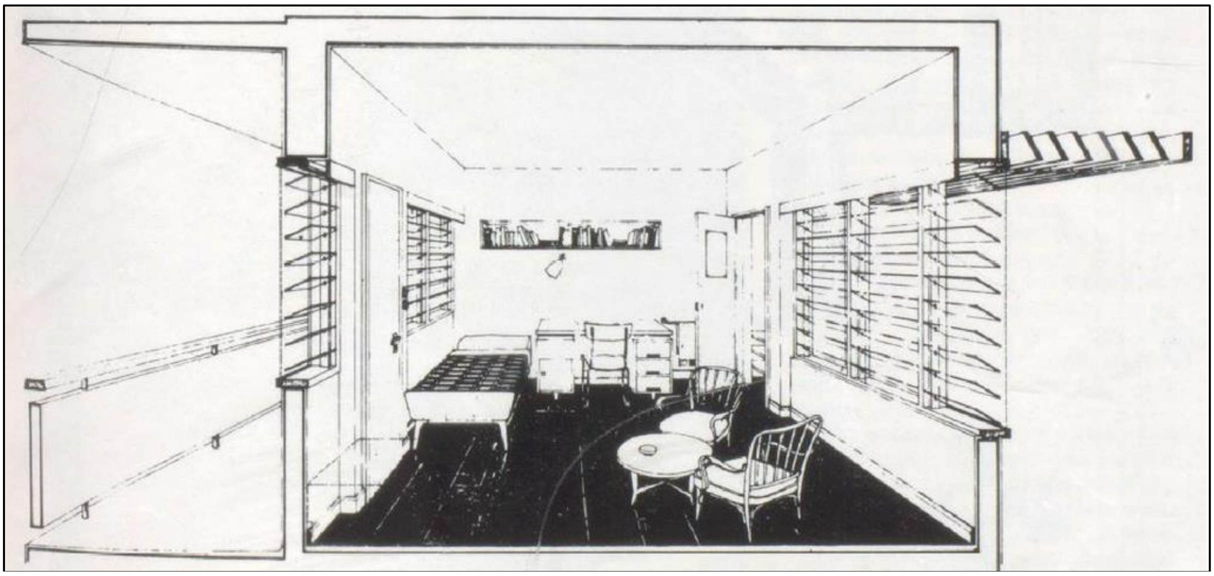


Figure 4.79 Section through a study bedroom of the new student residencies at the University of Ibadan, as designed by Design Group Architects – notice solid concrete walls, ceiling and floor slabs, glass louvred windows and sun breakers; source: Atkinson et al (1963, p.102).

and provided a central cafeteria. The cafeteria was designed to seat 360 at a time; the three residence blocks which accommodated 150 students each were close to and surrounded the cafeteria. The kitchen buildings were positioned downwind of the residential blocks. The kitchen quarters contained electrical facilities. Next to the kitchen was a laundry and both buildings opened into a service courtyard where clothes could be aired. The cafeteria was created with an octagonal form with an area of approximately 465m^2 (see Figure 4.81). The frame was predominantly constructed of reinforced concrete; the reinforced concrete flat roof was folded at eight ridges and valleys. The valleys converged at a central ring beam

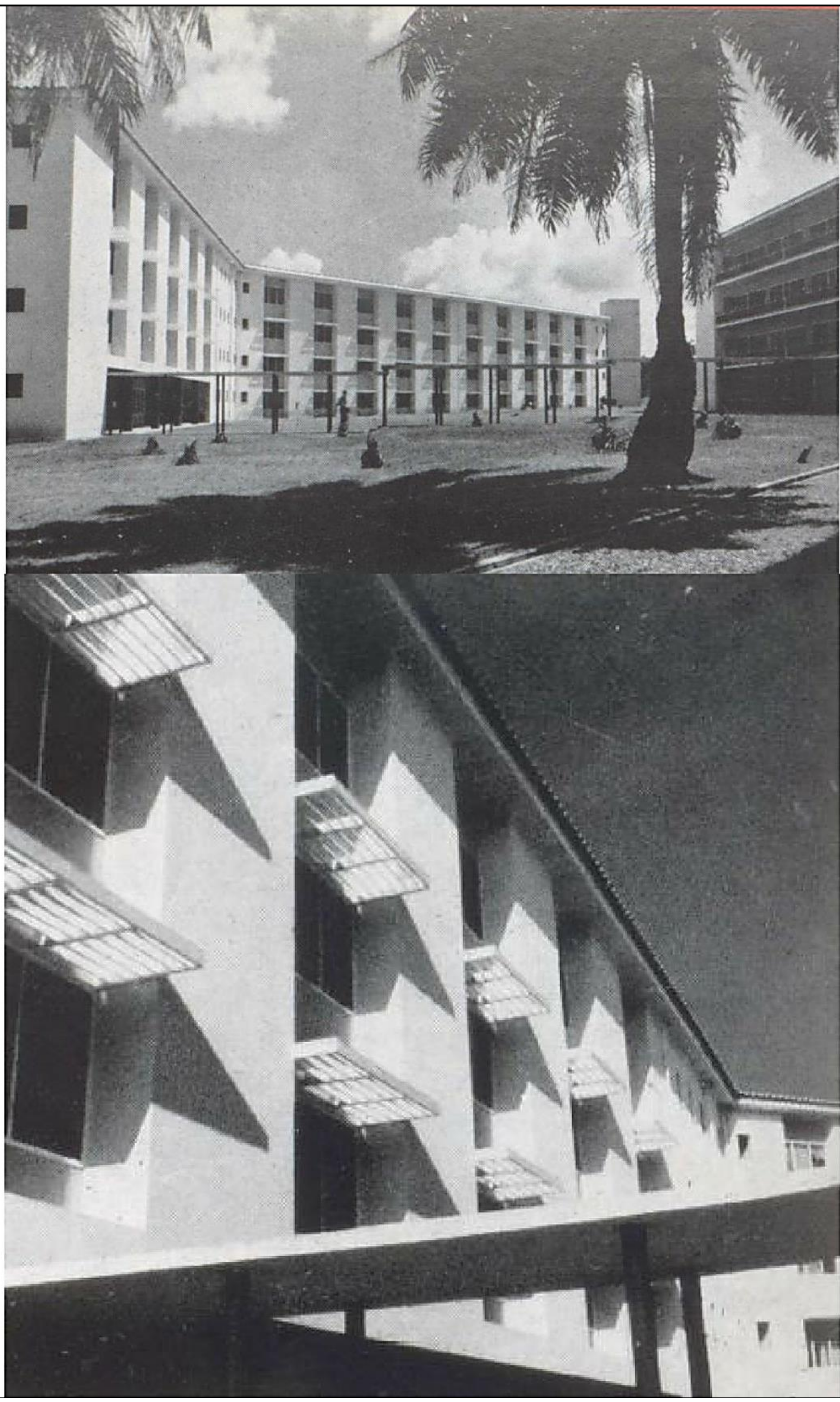


Figure 4.80 Top image – Exterior view of the student residential block; bottom image - detail view of sun breakers to study bedrooms; source: Atkinson et al (1963, p.101).

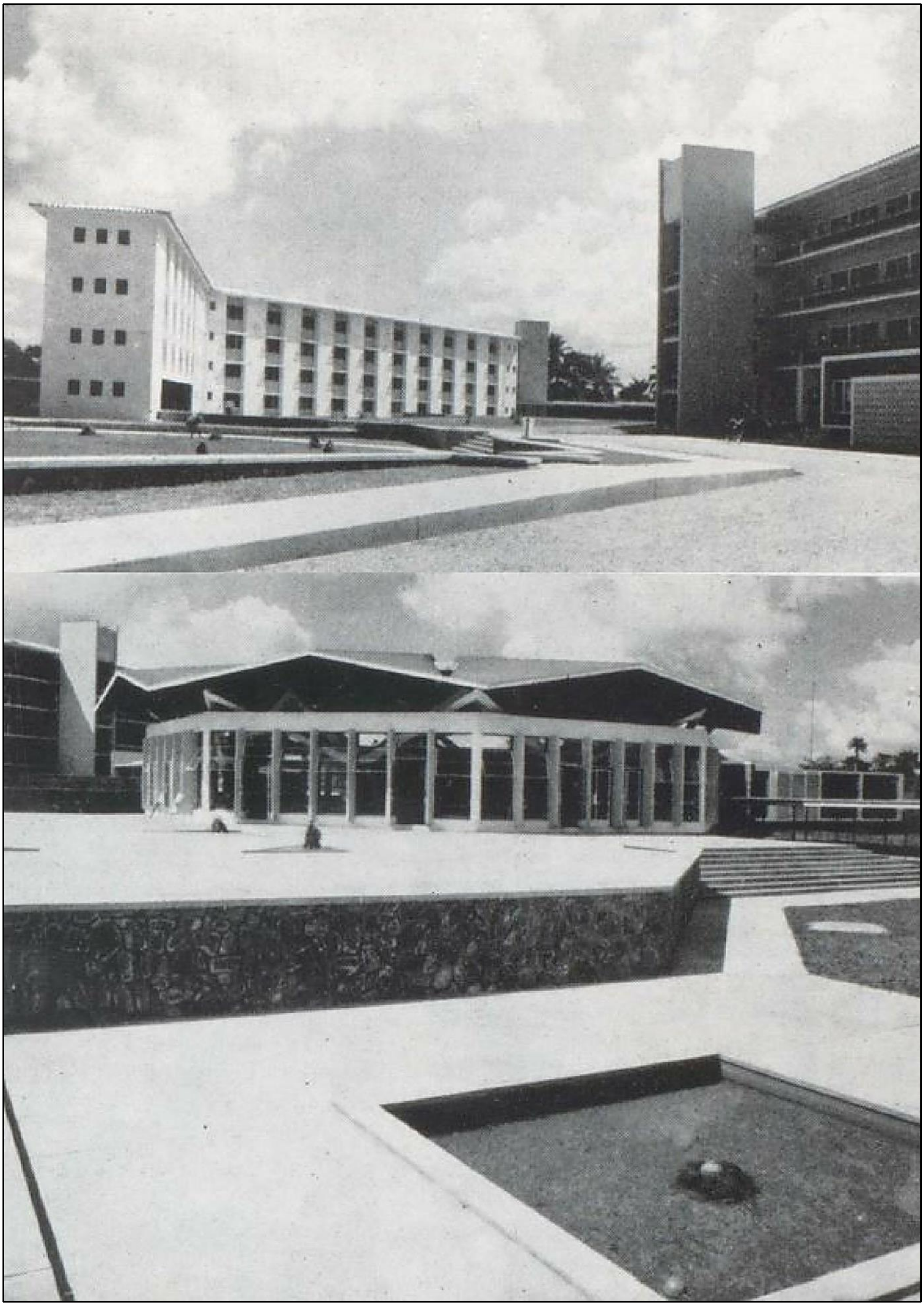


Figure 4.81 Top image – Exterior view of the student residential block, showing cantilevered walkway on the right-hand block; bottom image – exterior view of the dining hall/cafeteria (notice the geometric forms similar to Fry and Drew's tropical modernist architecture); source: Atkinson et al (1963, p.102).

which was covered by luminous fibre-glass dome-light. Eight columns supported the roof and were approximately 10m from the centre of the cafeteria. The columns were shortened at 2m above the floor with spread footings at their base for additional structural support. Four struts which travel from the top of each column to the roof's valley lines, were supported by a reinforced concrete joint. Along the cafeteria's northern side, a covered walkway was positioned to run from the hall to the common room and the first hostel block. Just like the cafeteria, the common room was built with a folded concrete slab roof. The hostel blocks were designed to be almost identical (see Figures 4.78 and 4.80). There were offices for porters and wardens, an administrative area, a dispensary and sickbay. Sanitary facilities included W.C.'s, urinals, showers and hand-wash basins. Utility rooms with power sockets, sinks and ironing boards, linen and box storage were located on each of the hostel's four floors. The double study-bedrooms on each floor measured 4.9m by 3.7m each, minus the two large inbuilt lockers (see Figure 4.79). The rooms were designed for cross-ventilation through mosquito-screened louvre windows. The student residences were built in reinforced concrete frames, with concrete blockwork panel walling. Cantilevered reinforced concrete balconies extended from the frames. The roof was made of steel trusses with reinforced asbestos roofing.

Nevertheless, these new residences deteriorated as well due to overcrowding (Livsey, 2014). Furthermore, the use of louvred windows and concrete grills-although strong climate-adaptive features-facilitated much noise pollution and made the student and staff residencies less popular with time (Ibid). The status of the university residence as elite, was consequently watered down. Lecturers began moving to elite suburbs. The south-west Nigerian elite suburbs developed after 1952 when there was a transfer of political power from the British to Nigerians (Mabogunje, 1962). The new government sent young men and women to Europe and America to acquire skills needed in building the economy (Ibid; Lloyd, Mabogunje & Awe, 1967). Therefore, a new category of Nigerians emerged who were exposed to and socio-economically buoyant enough to afford the living standards of developed countries. Professionals such as doctors, lawyers, entrepreneurs, teachers and executive civil servants made up this category. The housing of the elite suburbs featured modern housing with amenities such as piped water and electricity. The common types were self-contained bungalows, similar to the PWD European and tropical modernist bungalows (see Figure 4.82). Mabogunje (1962) mentions the open apartment house-type was popular in the suburbs. It was similar to but an improved version the chawl/block of flats/tenement block earlier mentioned. The open apartment house was more spacious and of better construction and design quality than the PWD tenements (see Figure 4.83). There were two flats per floor, each occupied by a different family. A flat usually consisted of three to four living areas with a kitchen, store and bathroom. The fabric of suburban housing was typically composed of concrete walls and floors, with glass windows

Figure 4.82 Suburban middle-high income modernist bungalow – notice solid concrete walls and glass louvred windows; source: Adunola & Ajibola (2016, p.15).

Figure 4.83 Suburban middle-high income modernist open apartment house; source: Adunola (2014, p.202).

Figure 4.84 Suburban middle-high income modernist two-storey housing unit (duplex); source: Adunola & Ajibola (2016, p.16).

(usually louvered), aluminium or asbestos roofing on timber framing.

Additionally, the transfer of government affected the European Reservations. The new south-west Nigerian elite consisting of new Nigerian government officials and professionals moved into the European Reservations. Thus, the Reservations became known as Government Residential Areas (GRAs) (Lloyd, Mabogunje & Awe, 1967). The PWD mansions built for executive British officials were given to top Nigerian officials. Two-bedroom mansions were originally built for British officials and their wives while their children remained in England (ibid). As such, some of these houses did not have sufficient space to those of the original Reservation mansions were built. The GRAs were expanded to accommodate more Nigerian politicians and professionals; new ones were built on land made available through the demolition of older colonial buildings such as the early colonial PWD houses and offices (Soyinka, 1994). The government built high-brow housing estates such as the Bodija Estate in Ibadan. The houses in the GRAs and elite estates were designed according to different price ranges. The higher-prices houses were multi-storey, had more rooms than the lower-priced houses which were usually bungalows. However, all the houses had gardens attached. The building envelopes of the new houses were modern: concrete/reinforced concrete frame, cement/concrete block walls, glass windows and asbestos/aluminium roofing or flat concrete slab roofs (Aboutorabi, 1985).

Prucnal-Ogunsote (1993) describes the houses of the GRAs and high-brow districts as *Nouveau Rich* architecture, which was birthed in the late Colonial era and carried on into post-independence or

Figure 4.85 Inside the Architecture House, Ikoyi, Lagos (designed by Oluwole Olumuyiwa), an example of Nouveau Rich domestic space – notice large windows, high level ceilings which admit air and light; source: Le Roux (2004, p.372).

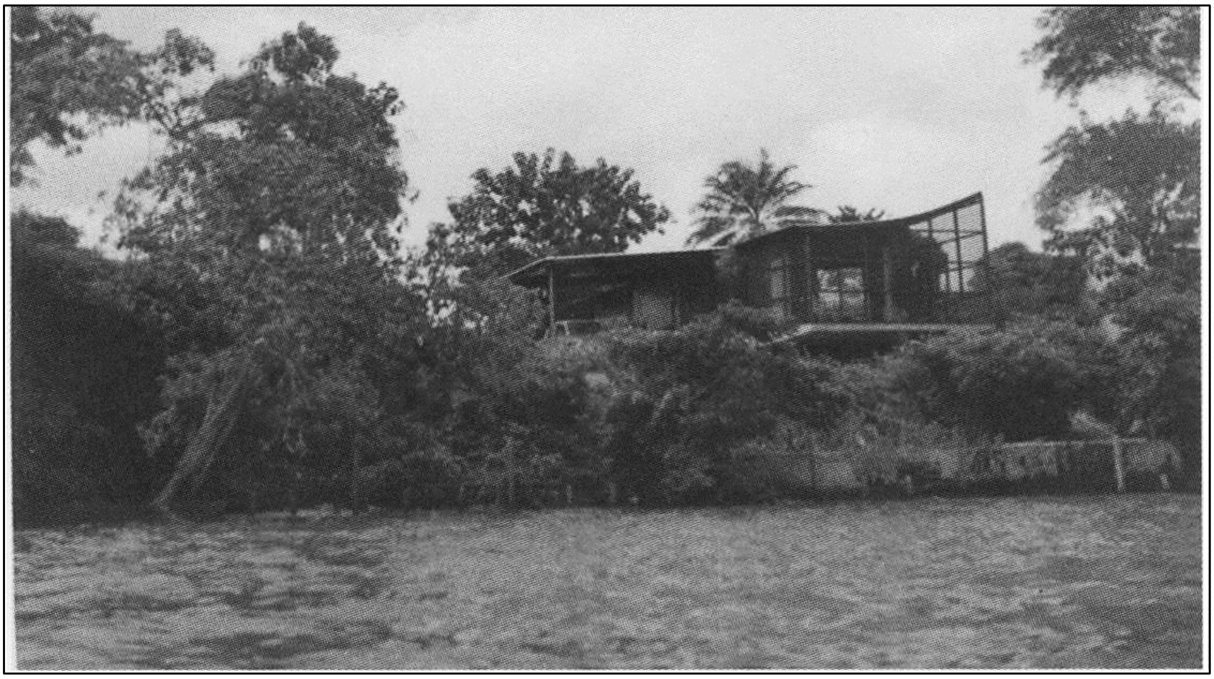


Figure 4.86 Alan Vaughan-Richards' House, Ikoyi, Lagos, an example of Nouveau Rich Housing; source: Le Roux (2004, p.375).

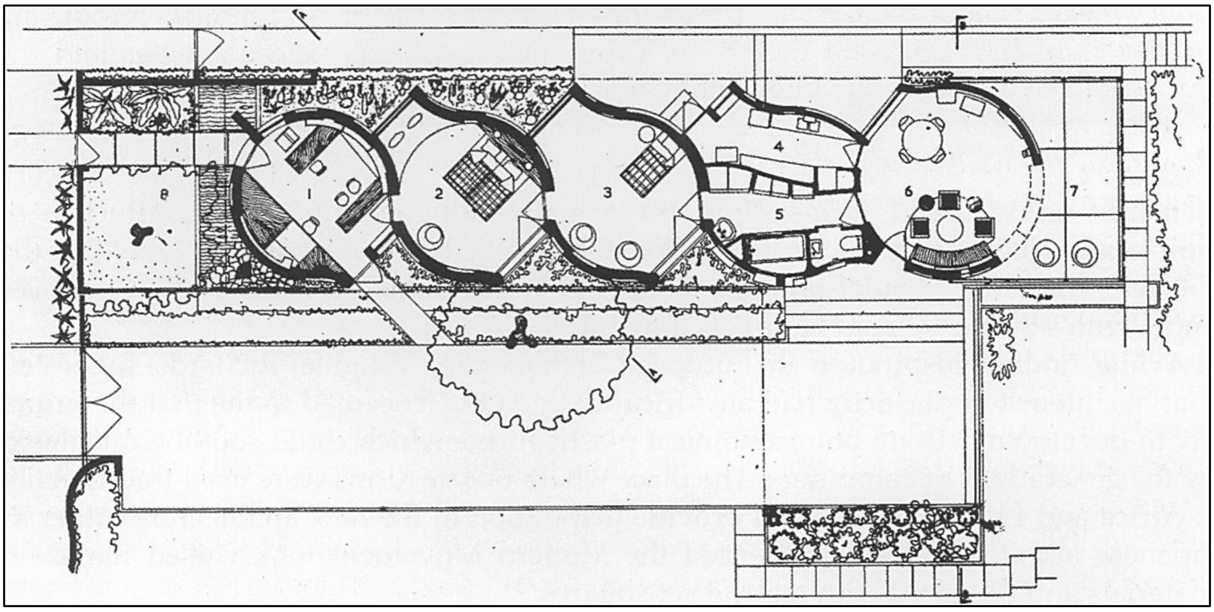


Figure 4.87 Floor plan of Alan Vaughan-Richards' House, Ikoyi, Lagos – notice peculiar shape of the plan, which seems symbolic of an indigenous pot; source: Le Roux (2004, p.375).

contemporary times. Accordingly, this architecture was infused with a lot of experimentation (see Figures 4.85 to 4.89). Foreign architectural firms such as Architects Co-Partnership, Godwin & Hopwood, Nickson & Borys cultivated climate-responsive design in the tropical modern style for elite private residences (Fry & Drew, 1964; Akinsemoyin & Vaughan-Richards, 1977). Nigerian architects became active and "… *insisted… that their field of operation required important architectural adaptations, most notably to Nigeria's climate*…" (Immerwahr, 2007, p.168). They featured climate-responsive features in their designs and attempted to further adapt the tropical modern style to the south-west Nigerian climate and culture by borrowing features of traditional Yoruba architecture and art (see Figure 4.87). Thus, it seems that Nouveau Rich architecture was an embellishment of tropical modern architecture using indigenous decorative motifs. An example is the Ola-Oluwakitan House where the functionality of formal architectural design was combined with the rustic artistic flexibility of Yoruba architecture (Uduku, 2006) (see Figures 4.88 and 4.89). Some of these houses were well-elevated above ground level, allowing air to move freely through and under the structure. Furthermore, interior spaces such as the living areas and dining rooms were double height or simply possessed higher ceilings than usual (see Figure 4.85). This style was associated with a fast-developing postmodern or contemporary architecture where dramatic elements such as semi-circular windows were being introduced into domestic facades (Prucnal-Ogunsote, 1993). The post-modern trend was based on the desire of architects in the south-west Nigerian context to exercise freedom in design. Therefore, the house would *"…pretend to look like a ship and sometimes it will tend to wear historical style…"* (Ibid, p.55).

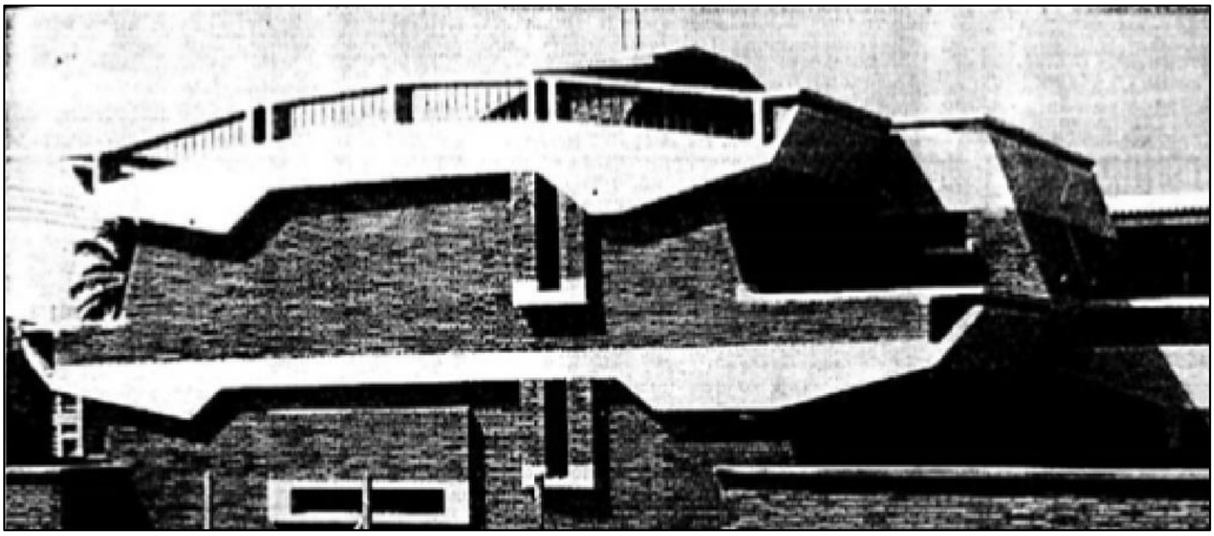


Figure 4.88 Ola-Oluwakitan House, Lagos, an example of Nouveau Rich housing – notice the building's expressive form; source: Uduku (2006, p.406).

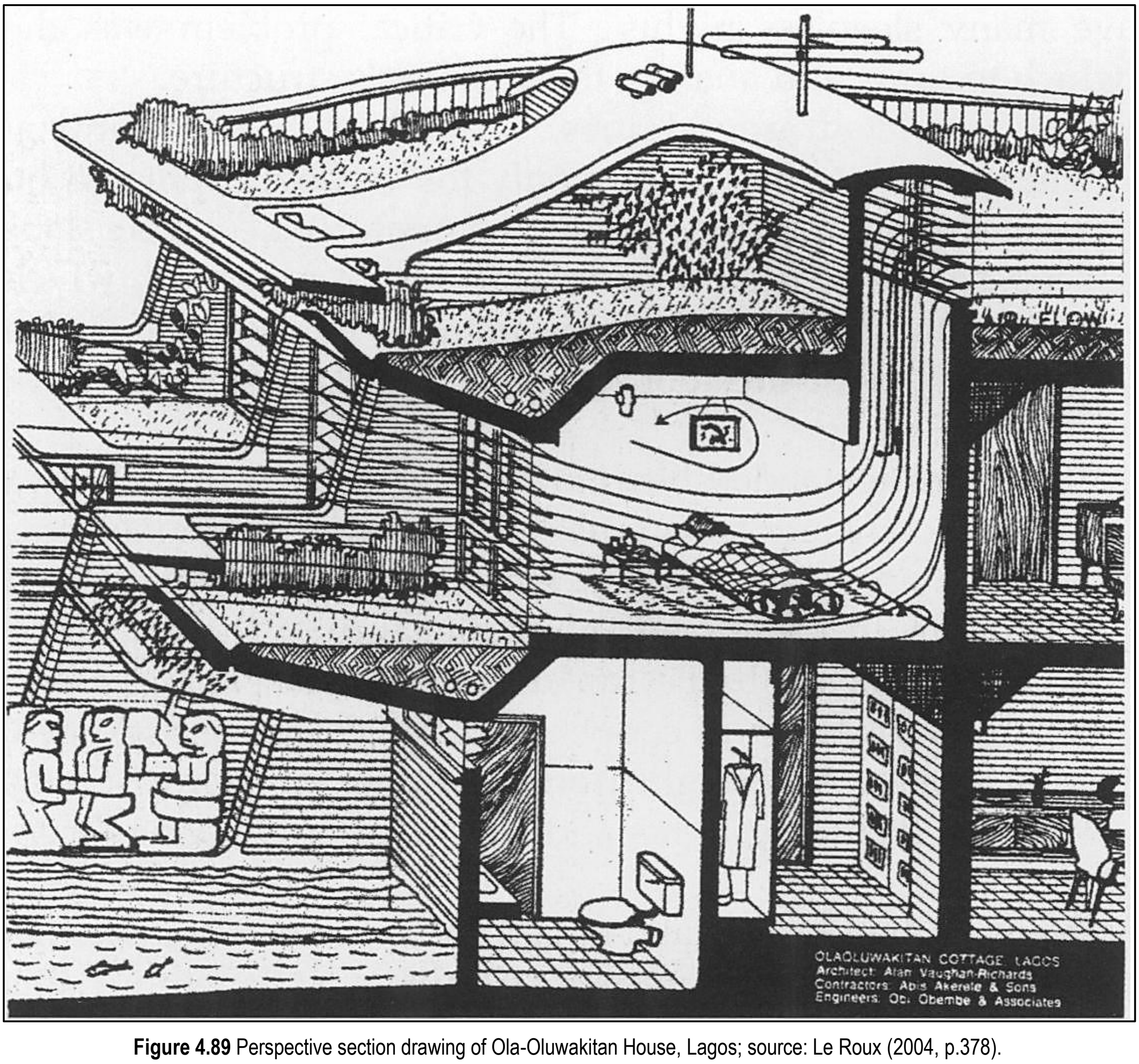


Figure 4.89 Perspective section drawing of Ola-Oluwakitan House, Lagos; source: Le Roux (2004, p.378).

4.3 Contemporary Collages – South-west Nigerian housing after 1952 (post-independence)

After Nigeria officially gained independence in 1960, urban planning fell short and private housing became more rampant, especially because of the high rates of urbanisation (Chokor, 2007). The extreme rates of urbanisation created a desperate need for housing to house the growing upper, middle and lower classes. In addition to the housing areas developed during the colonial era, new housing areas were developed by the government or private organisations and individuals backed by the government. As new housing developed and old housing (traditional and colonial house forms) remained, a common urban morphology emerged amongst post-independence south-west Nigerian cities.

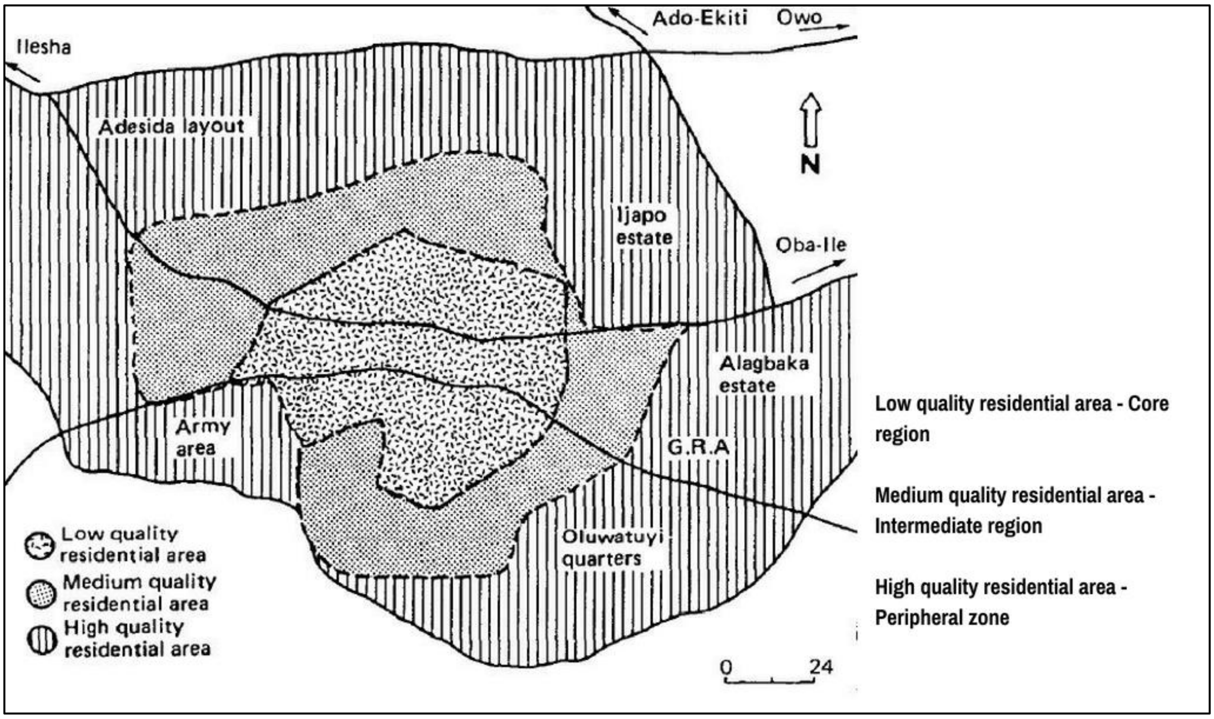


Figure 4.90 The three residential zones of a typical south-west Nigerian city (the image shows the residential zones in Akure, Ondo State); source: modified from Olorunfemi (1986, p.242).

This morphology is defined by zones where particular house types are more popular than others within each zone for various reasons. Three residential zones can be identified in Yoruba townships – the traditional centre, the transitional/intermediate and the peripheral/outskirts areas (Mabogunje, 1962; Olorunfemi, 1986; Jiboye & Ogunshakin, 2010) (see Figure 4.90). Although scarred, the traditional core has survived the changes that the region has endured through time. The core is occupied by low income earners who have stuck to the traditional vocations of farming, petty trading, crafts and so on. These people have remained attached to original family land, socio-cultural ties and systems (Chokor, 1993). The average household size is between 6-12 persons as the original extended Yoruba kinships are prominent in these parts (Yetunderonke, 2015; Jiboye, 2010). Here, the disintegrated traditional

Figure 4.91 *Owa*'s (King's) palace at Ilesha, Osun State – top image shows the anterior view and bottom image shows the main courtyard source: Fajuyigbe & Okunade (2015, p.38 (top image) and 42 (bottom image)).

compound houses remain and represent the oldest form of housing in the cities (Mabogunje, 1962). Consequently, only traces of the original compounds can be found at the traditional core (Ibid; Okeyinka & Odetoye, 2010). Where a compound house originally stood, there are now four or more houses, many of which have been extended to provide commercial spaces (Mabogunje, 1962; Oriye & Fakere, 2015) (see Figure 4.96). Therefore, the core is densely populated and social amenities are lacking. Accordingly, many core regions in contemporary Yoruba cities are classed as informal settlements with the lowest

Figure 4.92 *Owa*'s (King's) palace at Ilesha, Osun State – veranda of the main courtyard; source: Fajuyigbe & Okunade (2015, p.43).

Figure 4.93 *Owa*'s (King's) palace at Ilesha, Osun State – carved door and caryatid, modified in modern fashion (door shows neater carving than precolonial doors and caryatid is painted); source: Fajuyigbe & Okunade (2015, p.40).

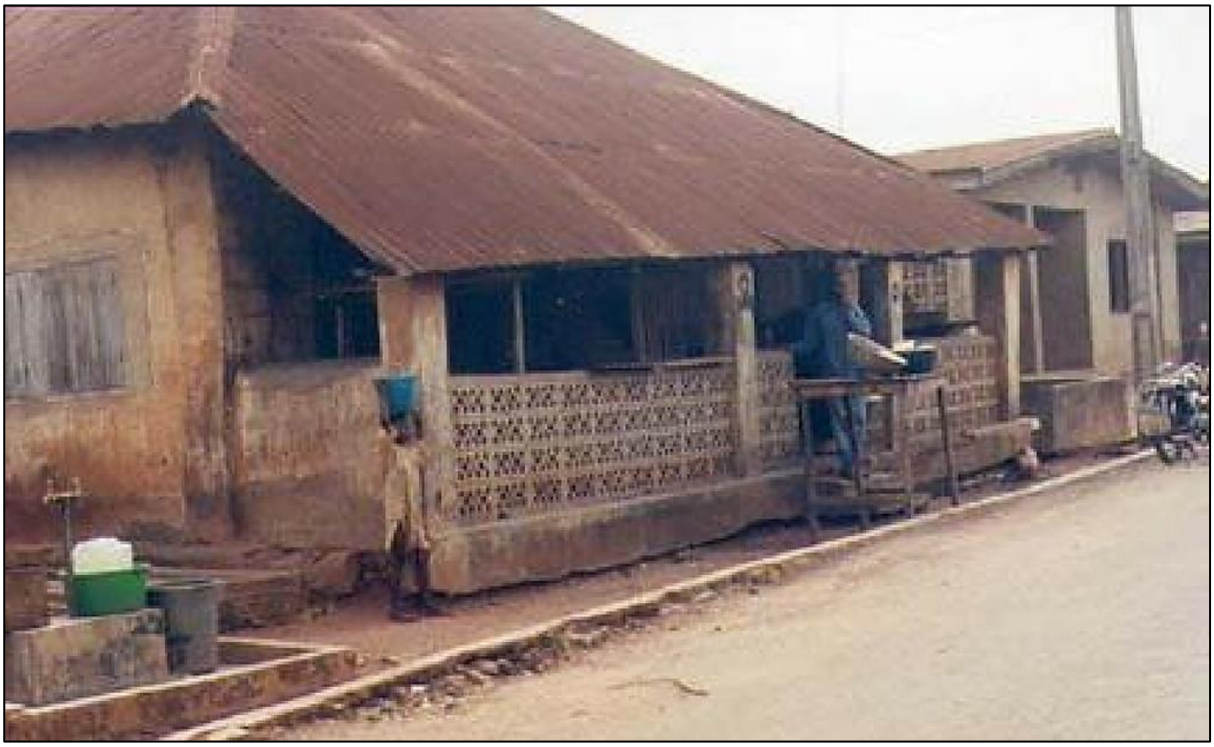


Figure 4.94 Modified traditional Orowa house typical of the core region; source: Adeokun, Ekhaese & Isaacs-Sodeye (2013, p.3).

Figure 4.95 Modified traditional courtyard house typical of the core region; source: Adeokun, Ekhaese & Isaacs-Sodeye (2013, p.4).

Figure 4.96 Modified traditional houses at the core, with anterior extensions used as shops; source: Oriye & Fakere (2015, p.479).

living and construction quality. The houses still bear the modified building envelopes acquired during the colonial period: cement-plastered mud/cement walls, corrugated iron roofs rusted with age (see Figures 4.94 and 4.95). Moreover, the capacity of the occupants to maintain their houses is low and this, coupled with the advanced age, causes a higher deterioration of the family houses at the core than in other zones (Jiboye, 2010; Fourchard, 2003). However, the traditional palaces remain well-preserved at the core as the traditional Yoruba rulers maintain their level of political influence post-independence (Adenle, 1969; Chokor, 1993) (see Figures 4.91, 4.92 and 4.93). Many have been updated using modern and contemporary construction such as the Lagos and *Ikere afin* described earlier (Dmochowski, 1990).

The intermediate zones are predominantly occupied by colonial buildings which include the Brazilian *Aguda* and *Saro* houses as well as the Afro-Brazilian rooming houses built between 1935 and 1960 (Jiboye, 2010). Therefore, the planned colonial indigenous reservations are referred to as the intermediate zone in contemporary times. Similar to the houses at the core, the Brazilian house-types have aged and continue to cater to larger numbers than the ideal. Another similarity to the core is that large numbers of the low-income economic bracket (artisans and petty traders) occupy the intermediate zones. Each house accommodates a range of 1-5 families, with each family having an average of 3-10 people (Adeniji & Ogundiji, 2009). Yetunderonke's 2015 study reveals that Brazilian houses' owners assert that overcrowding is a part of Yoruba cultural housing; they refer to the high number of occupants in the disintegrated compound houses which catered to extended families. However, the owners' motivation for excessive tenant numbers remains that more tenants indicate more income from rent. The quality of life and housing at the intermediate areas remains slightly better than that at the core, especially because colonial urban planning laws were implemented (see Figure 4.97). The building envelopes here are still built of solid walls (concrete, brick) with corrugated-iron roofing and timber, casement windows; however, many have deteriorated due to age and lack of maintenance (see Figure 4.98). Nevertheless, Jiboye (2010) and Fourchard (2003) state that the residents of the deteriorating Brazilian houses show a

Figure 4.97 Brazilian houses in the intermediate zone of Ibadan (Oke-Ado); source: Chokor (1990, p.266).

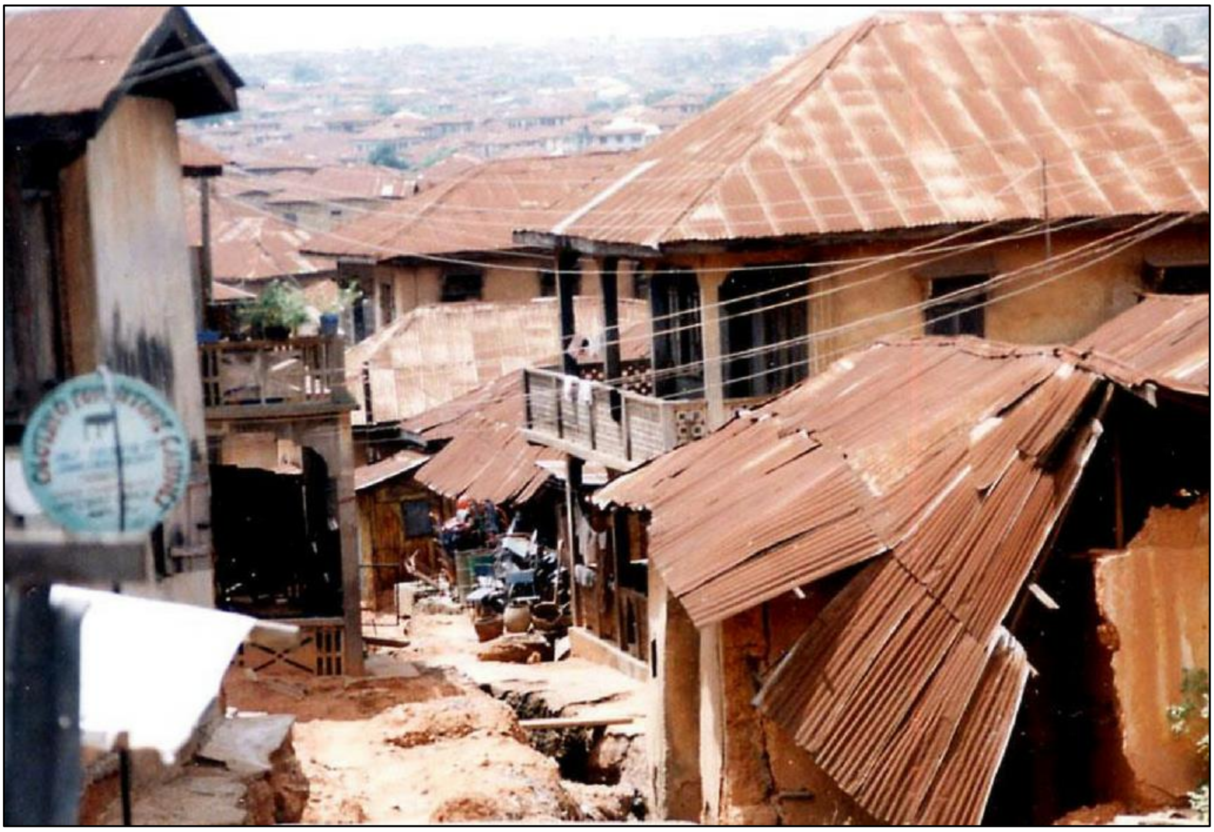
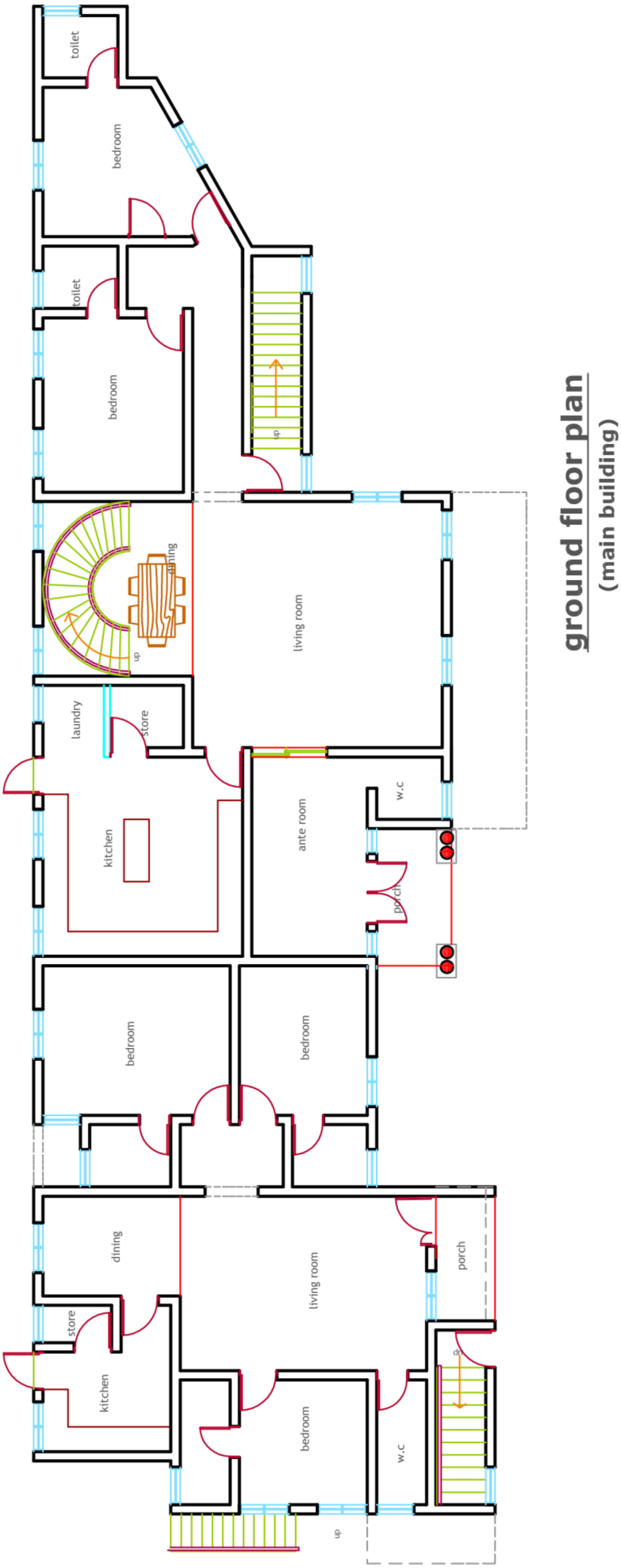


Figure 4.98 Deteriorated Brazilian houses in Ibadan; source: Fourchard (2003, p.8).

commitment to maintaining them by as much as is within their means. Additionally, the illegal informal settlements of the mid-late colonial period continue to persist on the edges of the intermediate zone (Aboutorabi, 1985; Fourchard, 2003; Agbola & Agunbiade, 2009; Daniel, Wapwera, Akande, Musa & Aliyu, 2015). Furthermore, they continue to display the three types of informal settlement envelopes. The existence of compound house remnants, informal settlements and Brazilian house-types at the core and intermediary zones, show the capacity of these historic types to exist for 60 years and above (Jiboye & Ogunshakin, 2010).

At the periphery/outskirts, there is the highest degree of diversity, the highest number of housing units and the least population density (Jiboye, 2010; Jiboye, 2014). The GRAs, low-cost and elite government estates, University residences and contemporary neighbourhoods are situated here (Olorunfemi, 1986; Ibid). Most of the colonial house-types (PWD housing in the GRAs) in this region remain intact apart from deterioration due to age (Home, 1997; Livsey, 2014). However, the GRAs display newer housing models which may be classified as mansions with many, luxurious spaces (Prucnal-Ogunsote, 1993) (see sheets 4.1 to 4.9). These contemporary mansions serve top government officials and elite civilians. Furthermore, new post-independence developments in this area include government estates, privately-owned or privately-developed housing estates approved by the government (PWD) and neighbourhoods featuring houses built by individuals (Olorunfemi 1985; Jiboye, 2010). The new government or government-approved estates are patterned after the low-density housing and garden layout of the Reservations (Lloyd, Mabogunje & Awe, 1967; King, 1984; Prucnal-Ogunsote, 1993). Some of these new estates were built to accommodate upper-middle to middle class professionals such as lecturers, doctors, lawyers and civil servants in apartment blocks and medium to small bungalows. Differently in the privately-developed areas, a man could buy a plot of land and build a house for his immediate nuclear family and a few relatives, to his own tastes (Lloyd, Mabogunje & Awe, 1967). Nevertheless, he had no control over the houses of his neighbours. As such, individuals build their houses with individual tastes dependent on money and background rather than at the core and intermediary (Mabogunje; 1962; Jiboye, 2010).

In the privately-developed areas, individuals build tenement blocks to make profits from renting the flats (Sheets 4.10 to 4.17 show the design of a typical contemporary tenement block of flats). Additionally, the private neighbourhoods feature mixed ethnicities and varying levels of income (Jiboye, 2010). Thus, there is more variety of domestic architectural styles, in privately-developed residential residential areas. Olayemi (1980) and Fourchard (2003) add that this variety includes a low-income bracket who live in houses that may be termed as informal settlements. However, unlike the informal settlements at the edges of the planned intermediate zones, the houses are built on legally obtained land. According to Olayemi (1980), these post-independence informal settlements are occupied by people with more education and



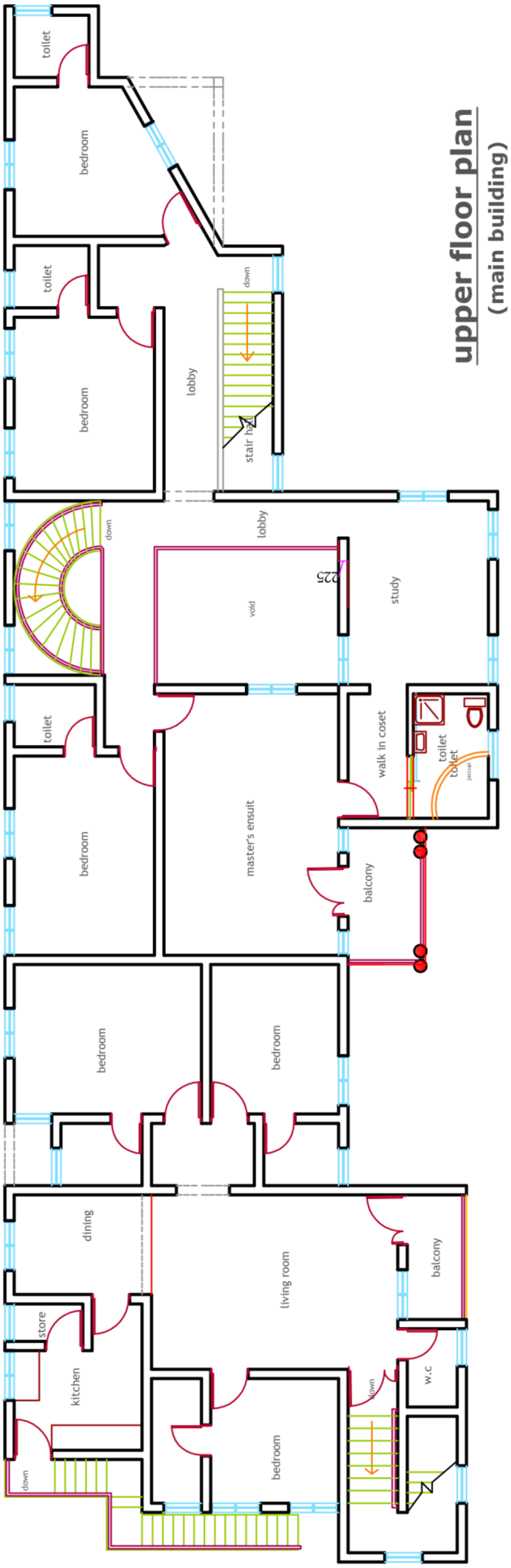
Sheet 4.1

Ground Floor Plan

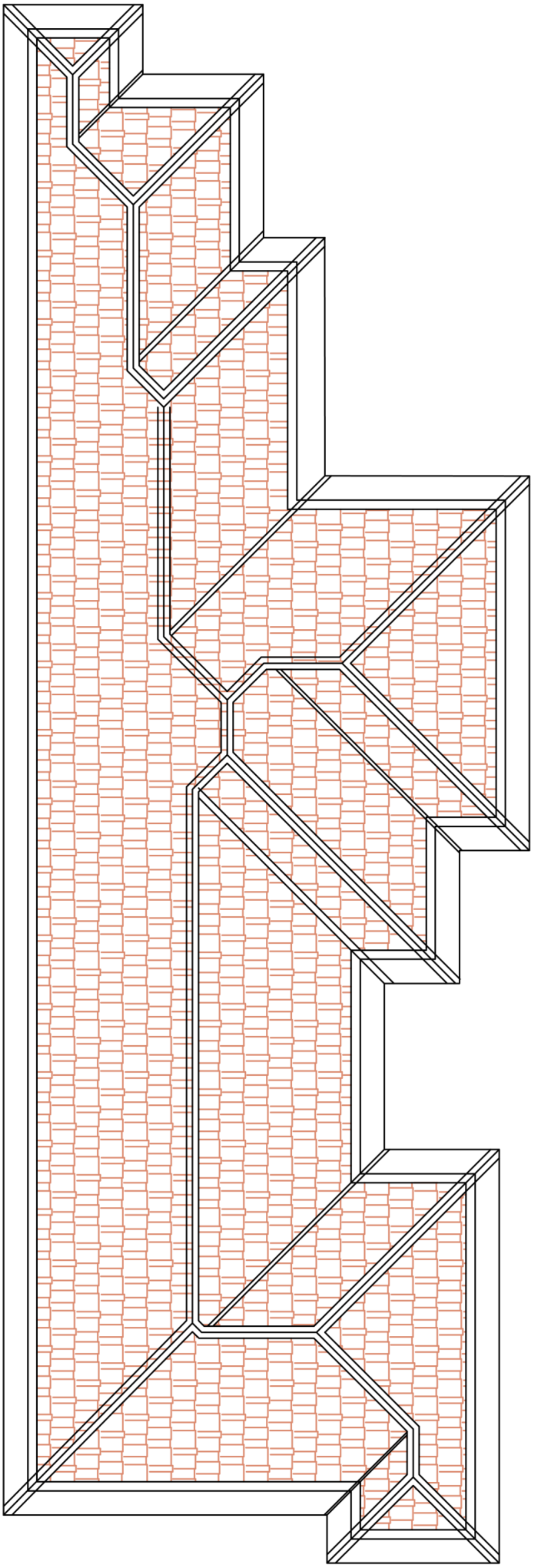
Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State

Scale: 1:150

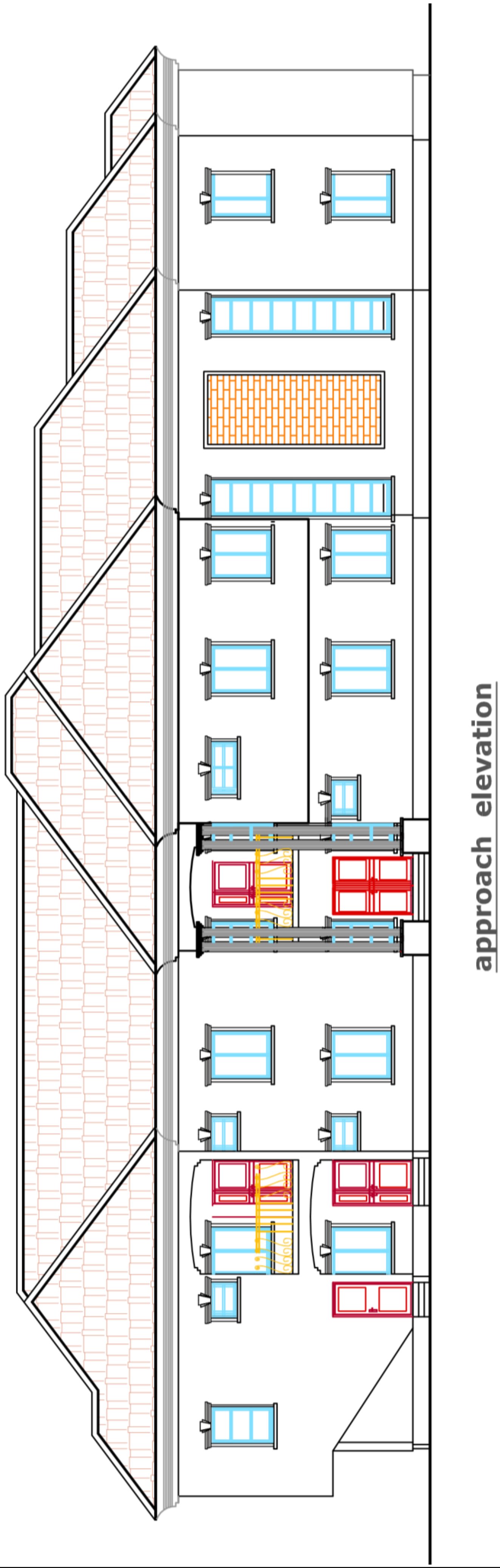
Source: author's study



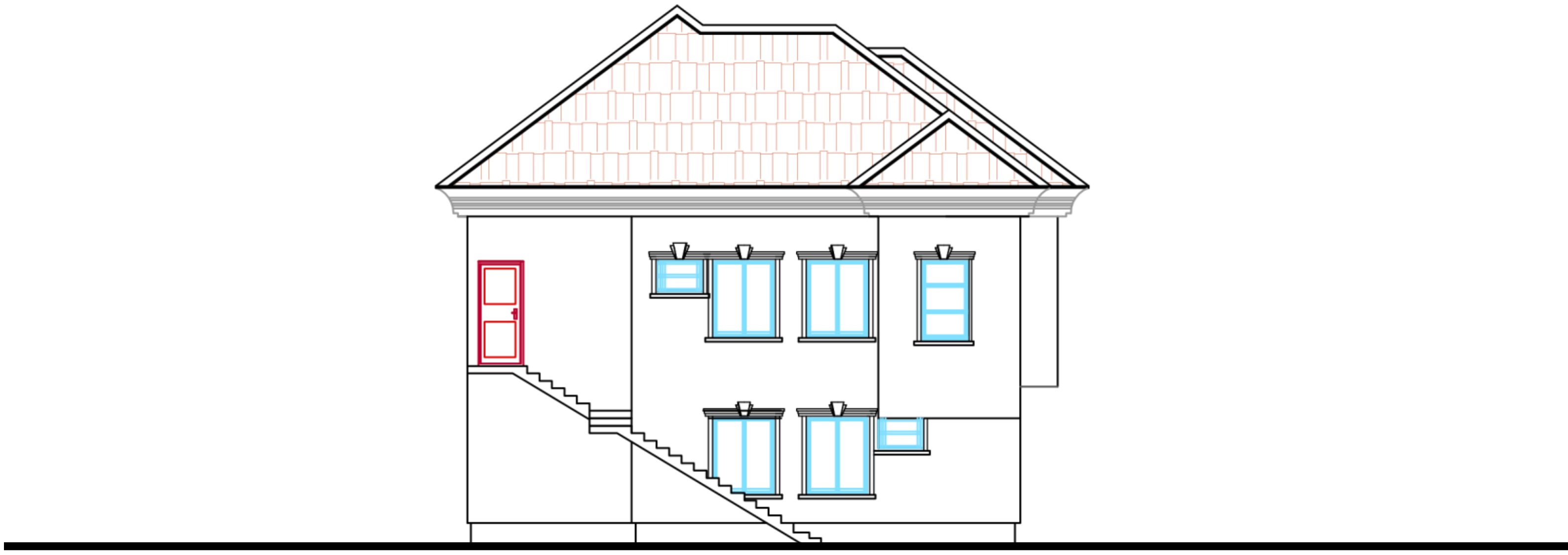
Sheet 4.2	**First Floor Plan** Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State	Scale: 1:150 Source: author's study



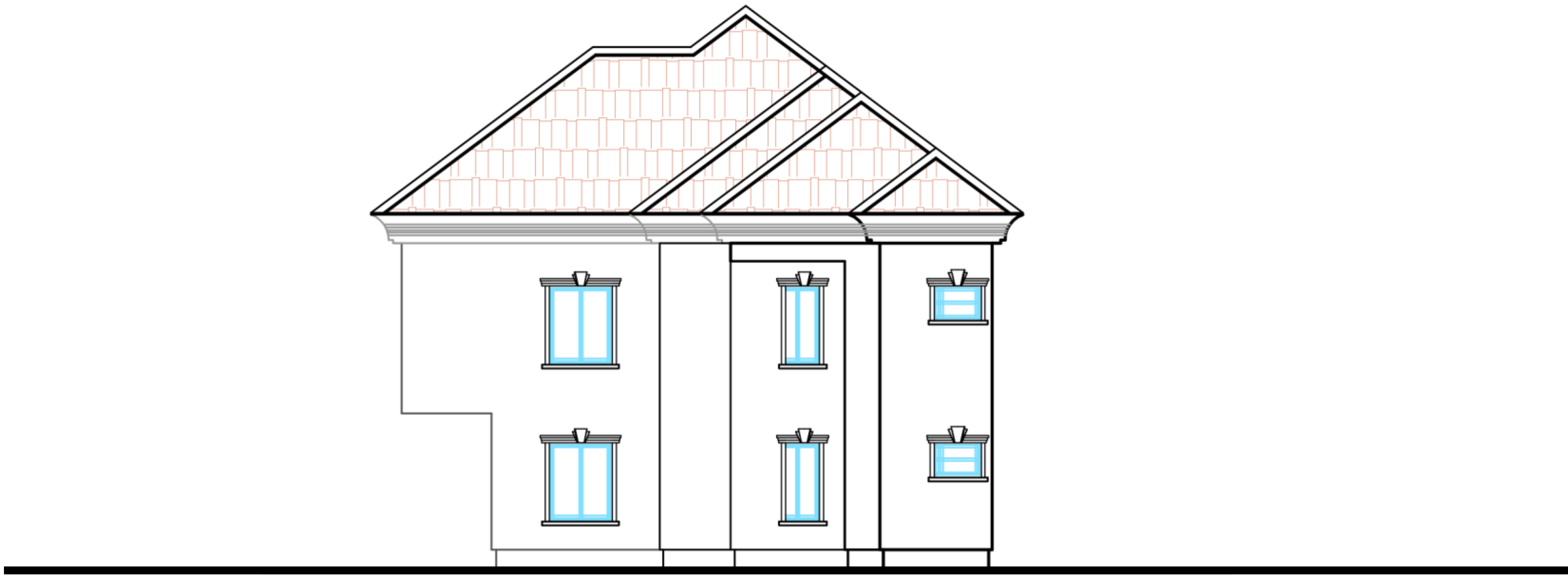
Sheet 4.3	**Roof Plan** Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State	Scale: 1:150 Source: author's study



Sheet 4.4	**Approach Elevation** Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State	Scale: 1:150 Source: author's study

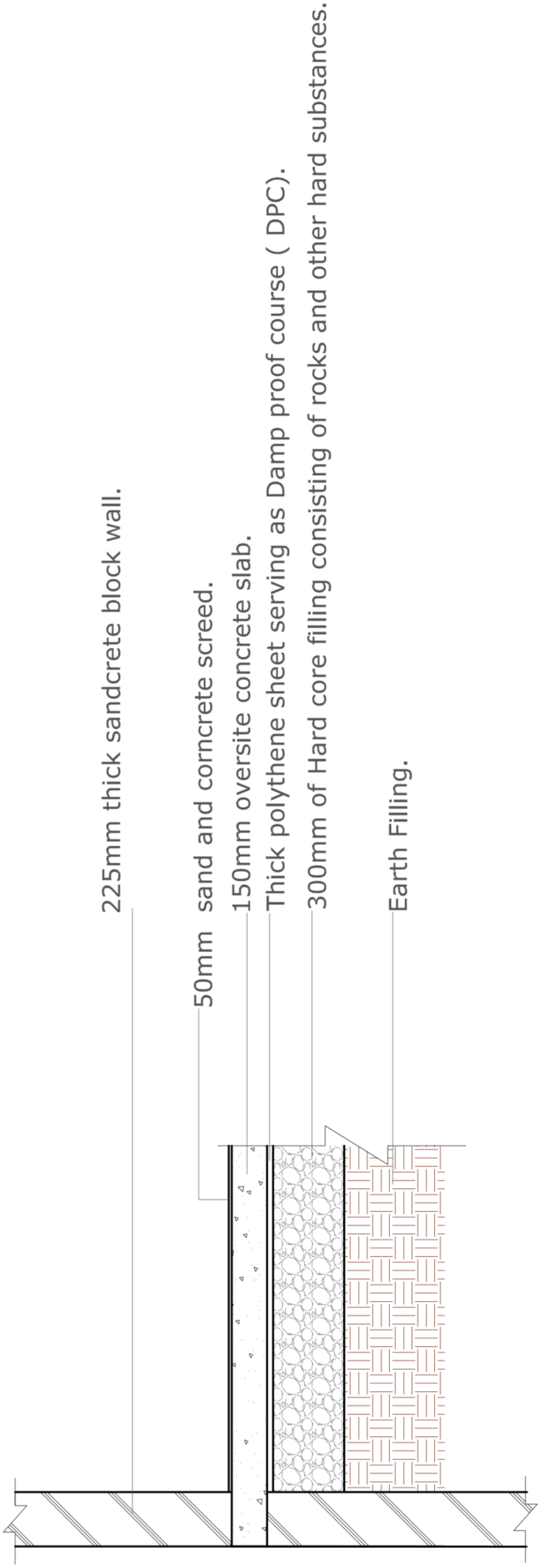


left side elevation



right side elevation

Sheet 4.5	**Left and right elevations** Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State	Scale: 1:150 Source: author's study



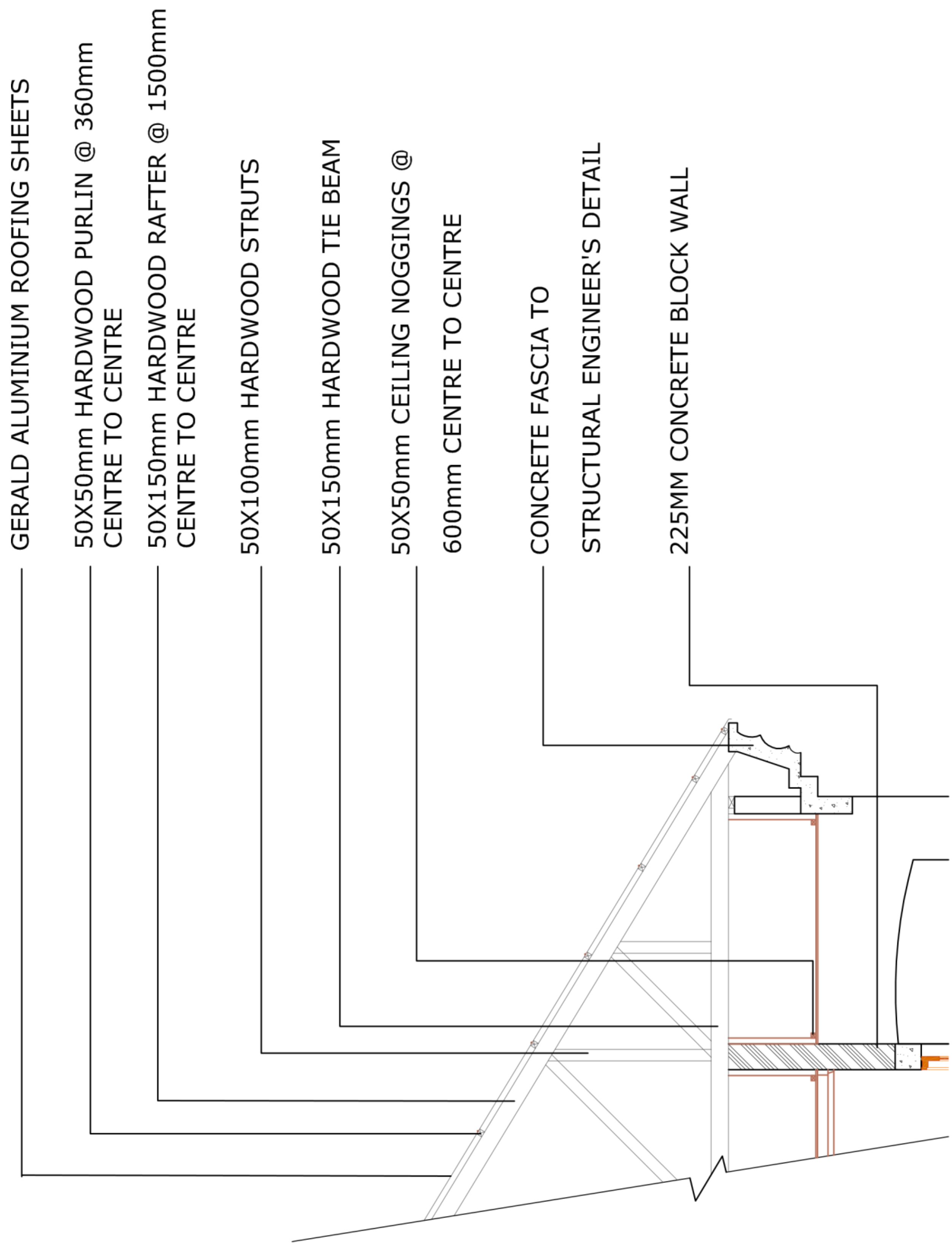
Sheet 4.6

Wall and floor detail

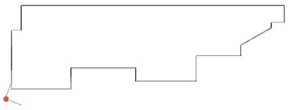
Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State

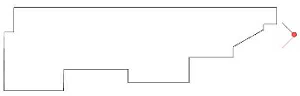
Scale: 1:40

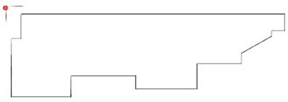
Source: author's study



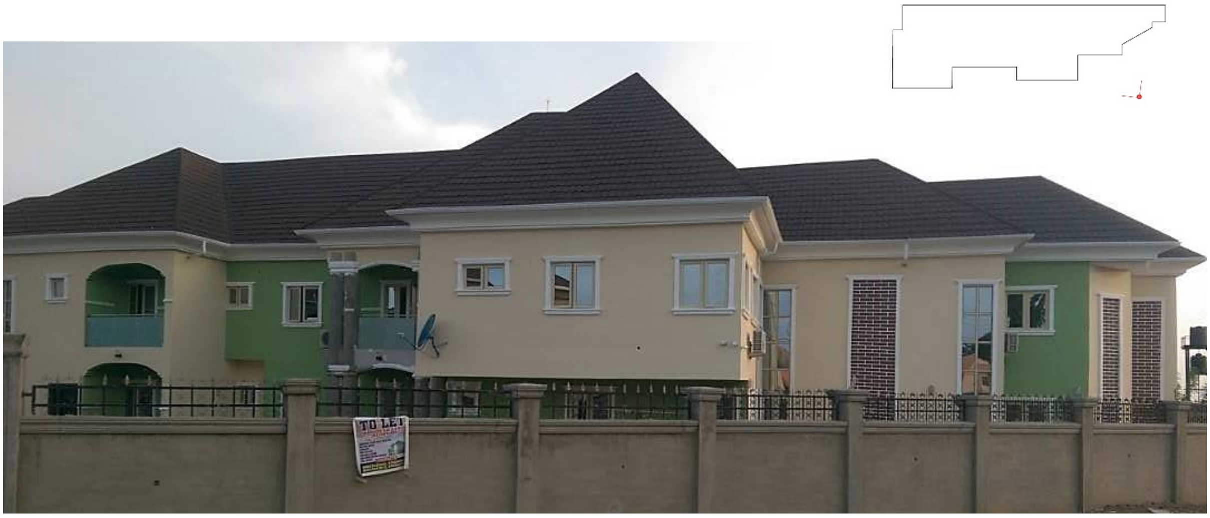
Sheet 4.7	**Roof eave detail** Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State	Scale: 1:75 Source: author's study



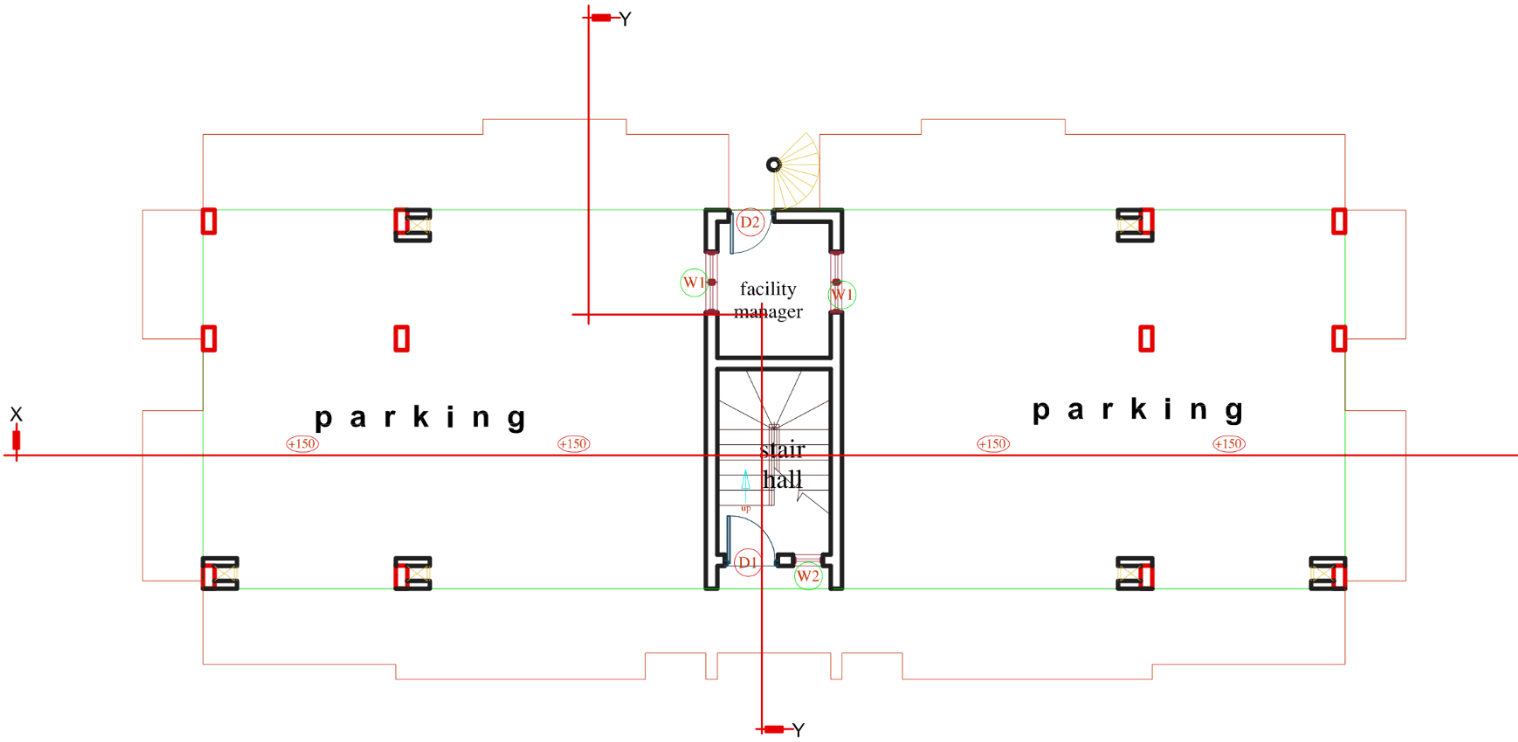




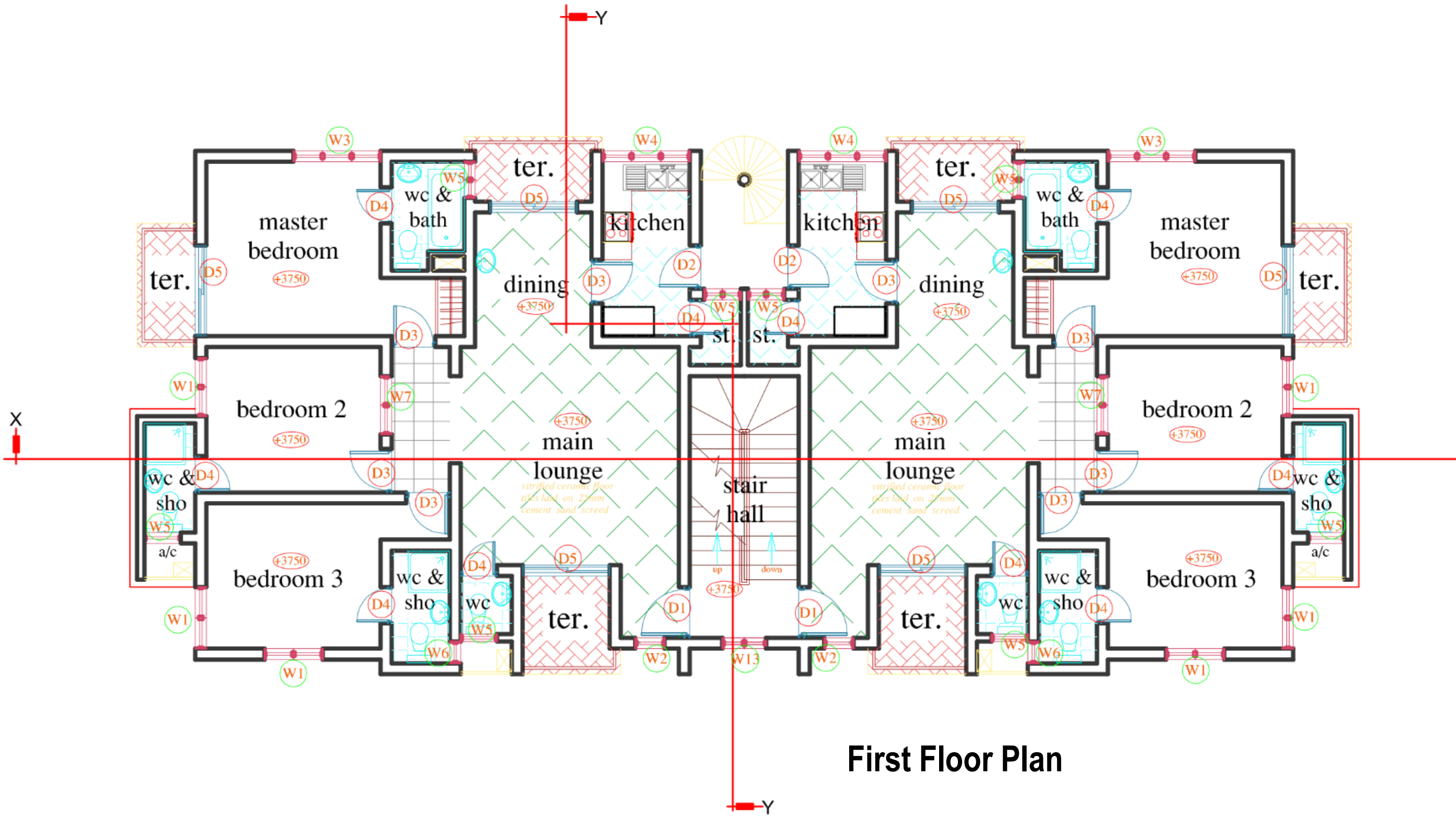
Sheet 4.8	**3D perspectives** **Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State**	**Scale: none** **Source: author's study**



Sheet 4.9	**Exterior Views** **Contemporary elite housing in Kolapo Ishola GRA, Ibadan, Oyo State**	**Scale: none** **Source: author's study**



Ground Floor Plan (for parking)



First Floor Plan

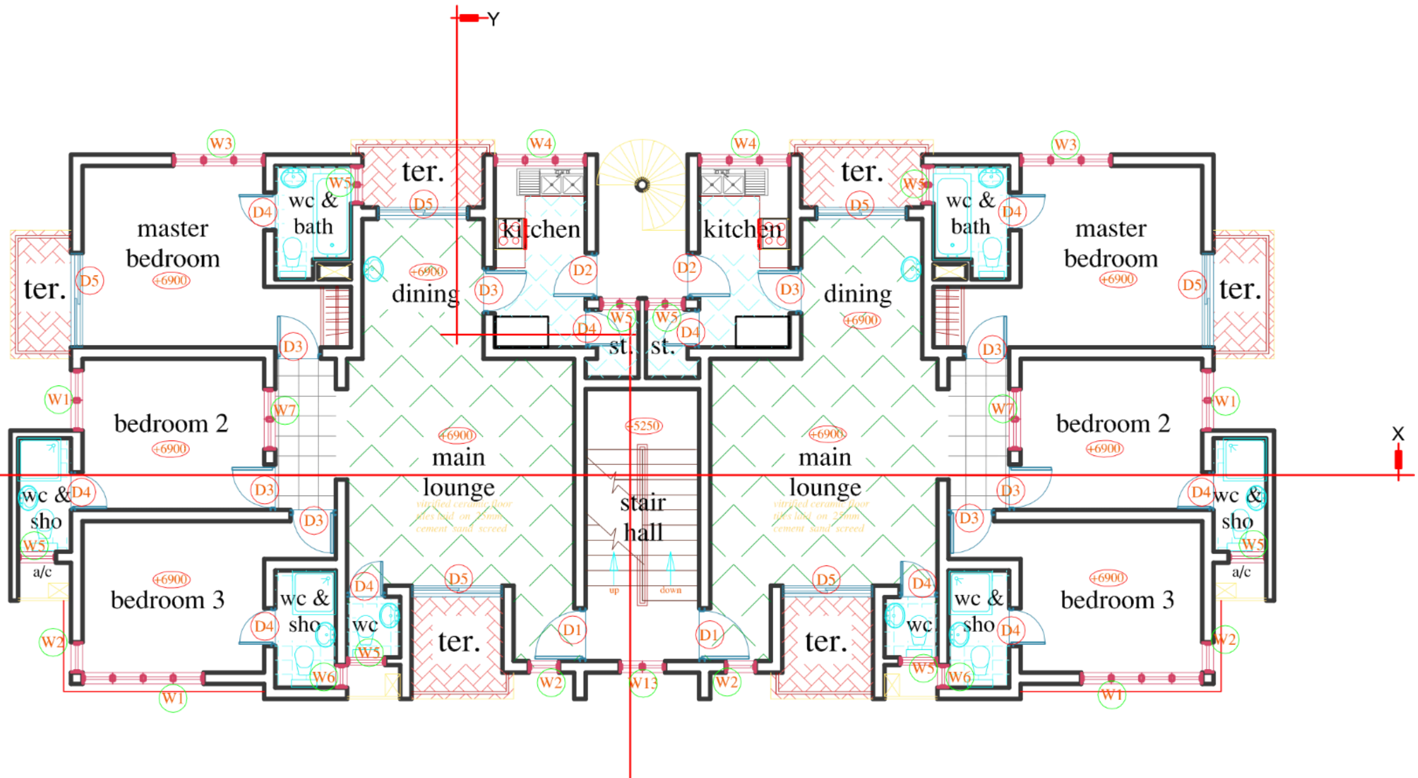
Sheet 4.10

Floor Plans

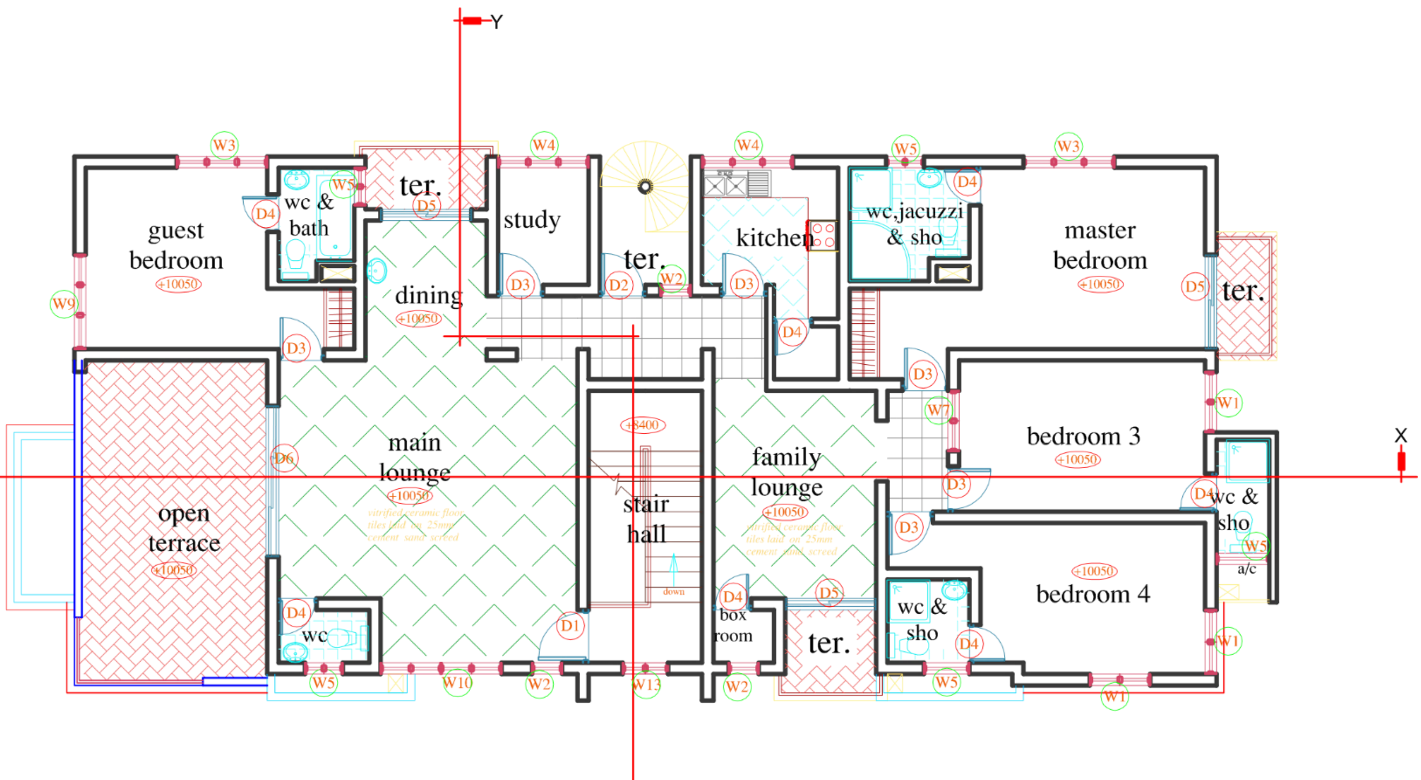
Contemporary block of 5 flats in Yaba, Lagos State

Scale: 1:150

Source: author's study

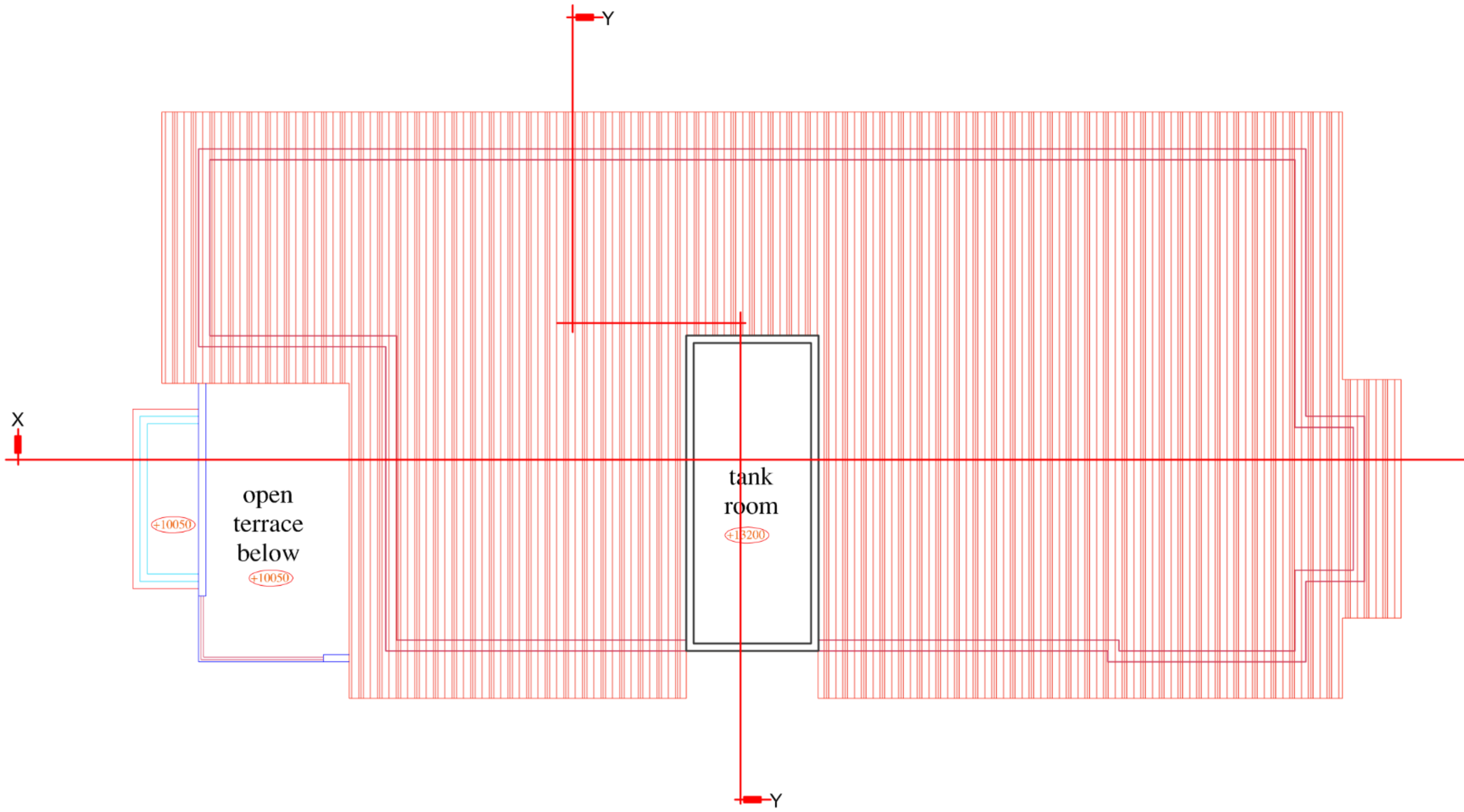


Second Floor Plan

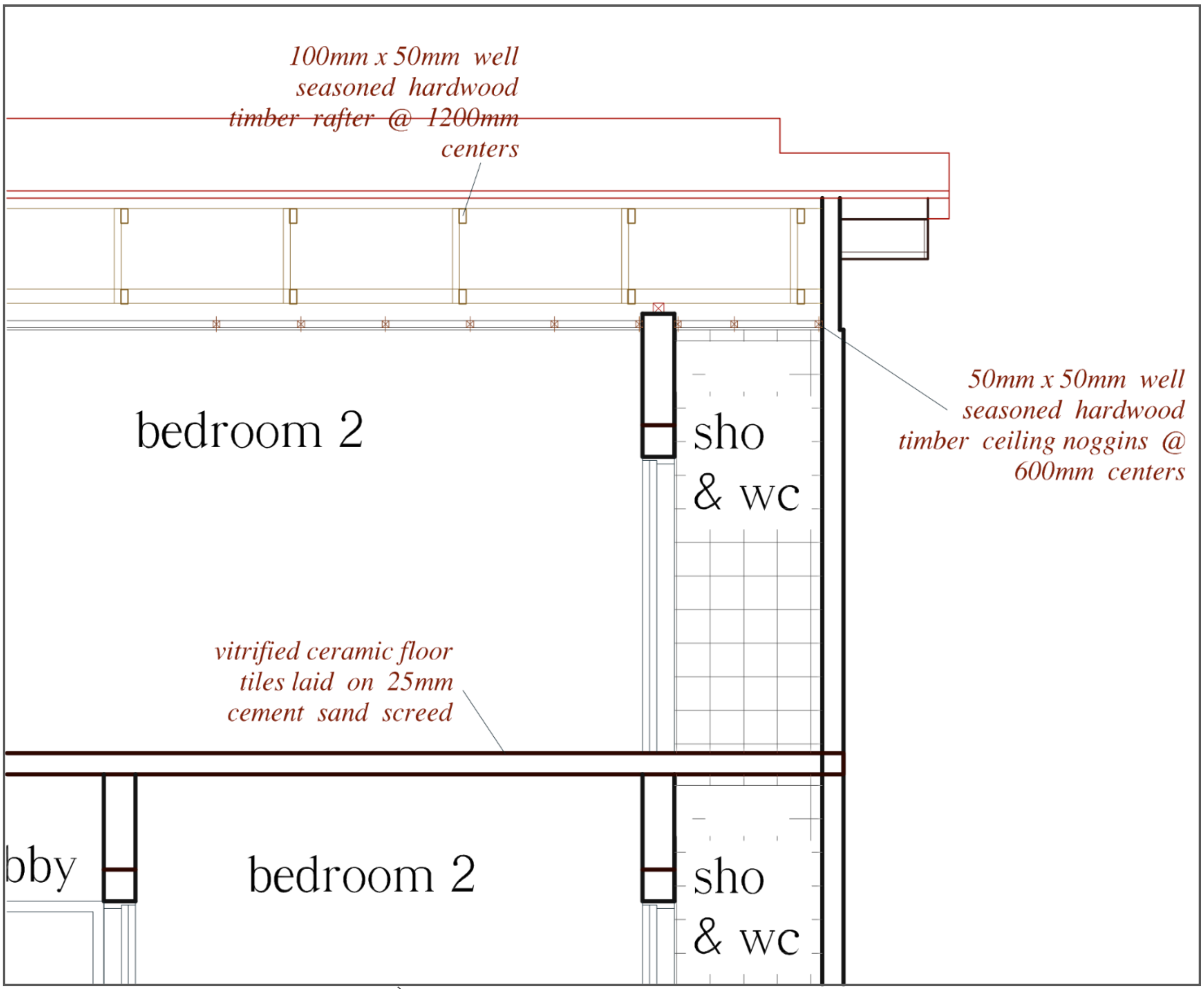


Third (Pent house) Floor Plan

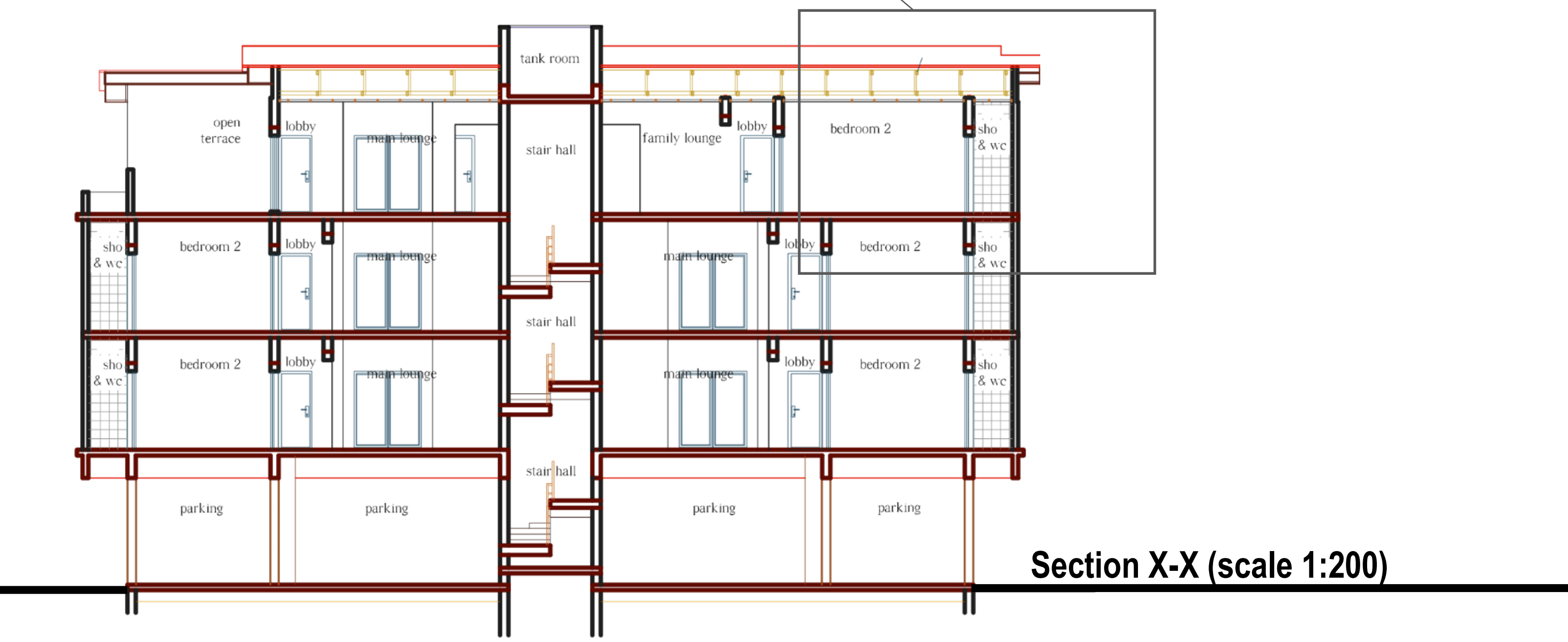
Sheet 4.11	**Floor Plans** Contemporary block of 5 flats in Yaba, Lagos State	Scale: 1:150 Source: author's study



Sheet 4.12	**Roof Plan** **Contemporary block of 5 flats in Yaba, Lagos State**	**Scale: 1:150** **Source: author's study**

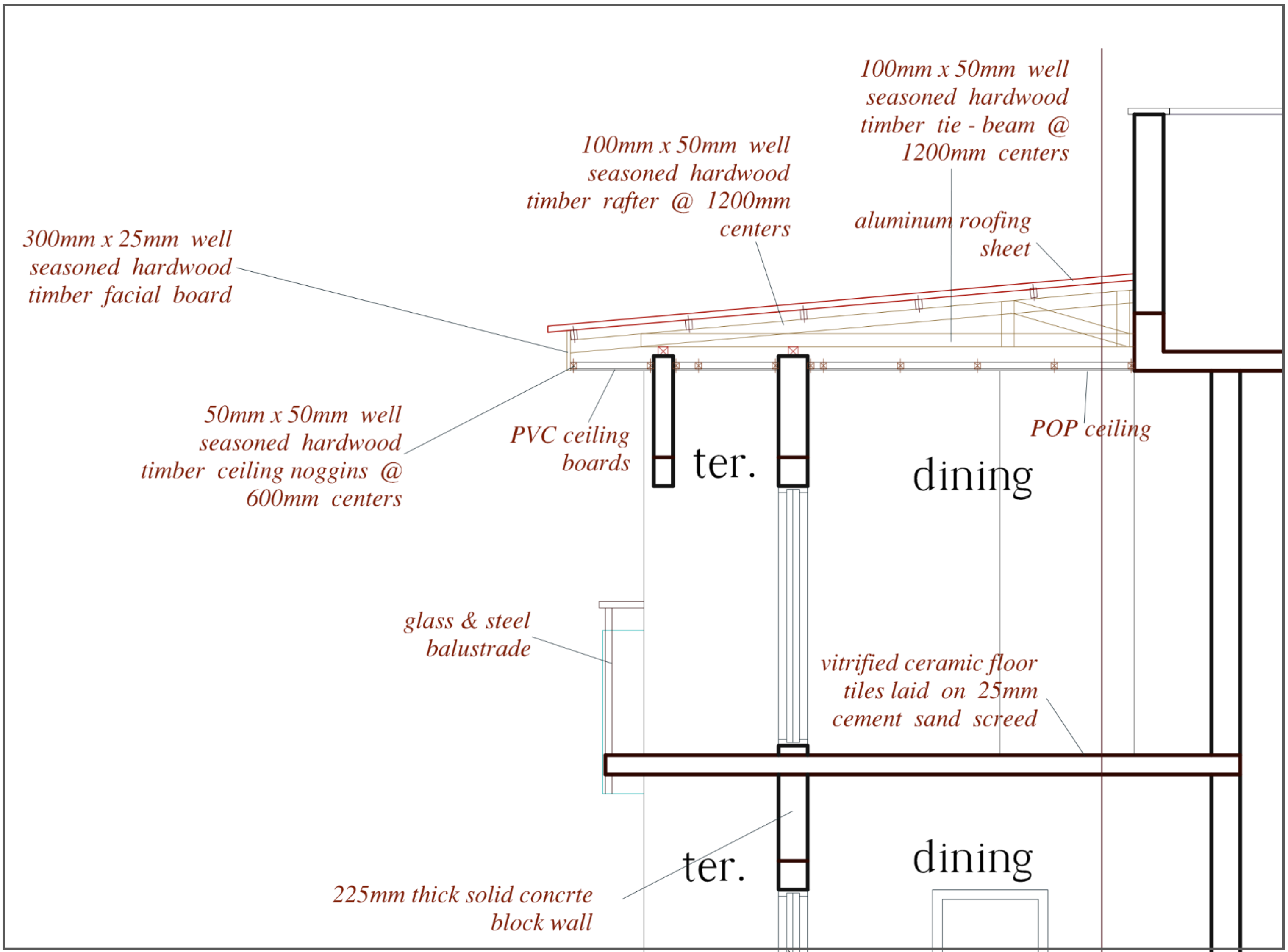


Blow-out of Section X-X (scale 1:50)

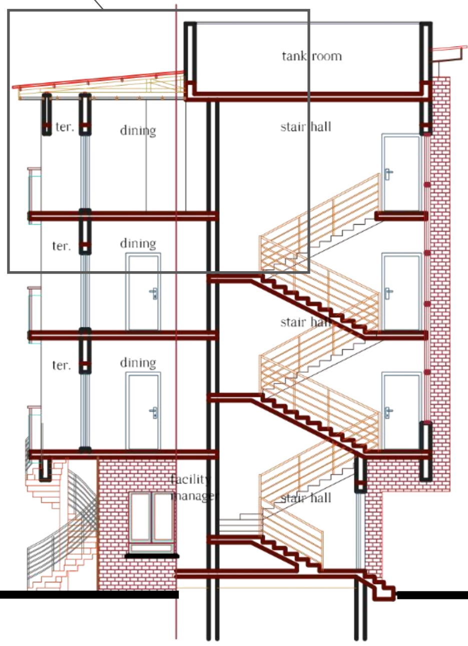


Section X-X (scale 1:200)

Sheet 4.13	Section X-X Contemporary block of 5 flats in Yaba, Lagos State	Scale: multi Source: author's study

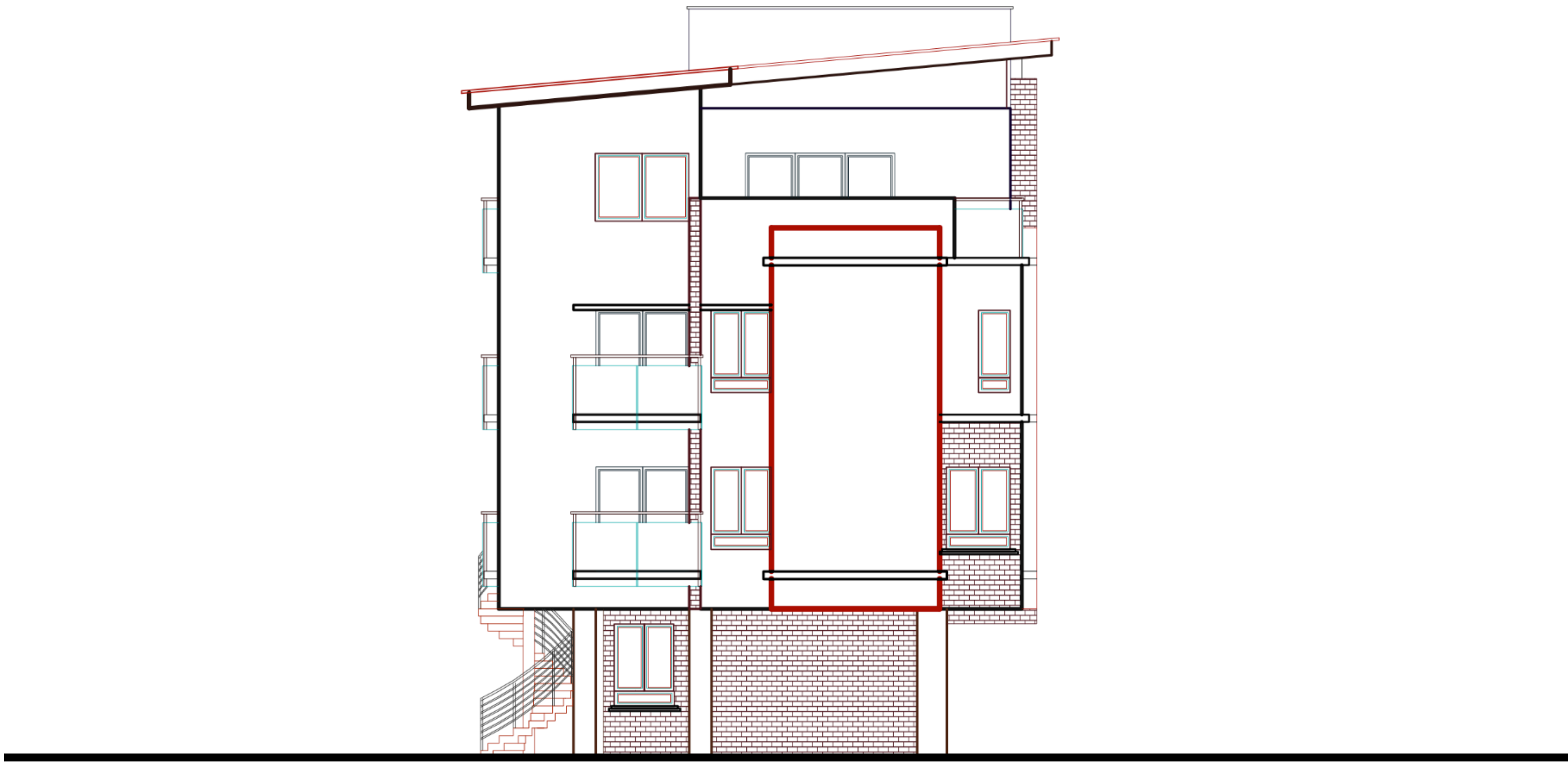


Blow-out of Section Y-Y (scale 1:50)



Section Y-Y (scale 1:200)

Sheet 4.14	**Section Y-Y** **Contemporary block of 5 flats in Yaba, Lagos State**	**Scale: multi** **Source: author's study**

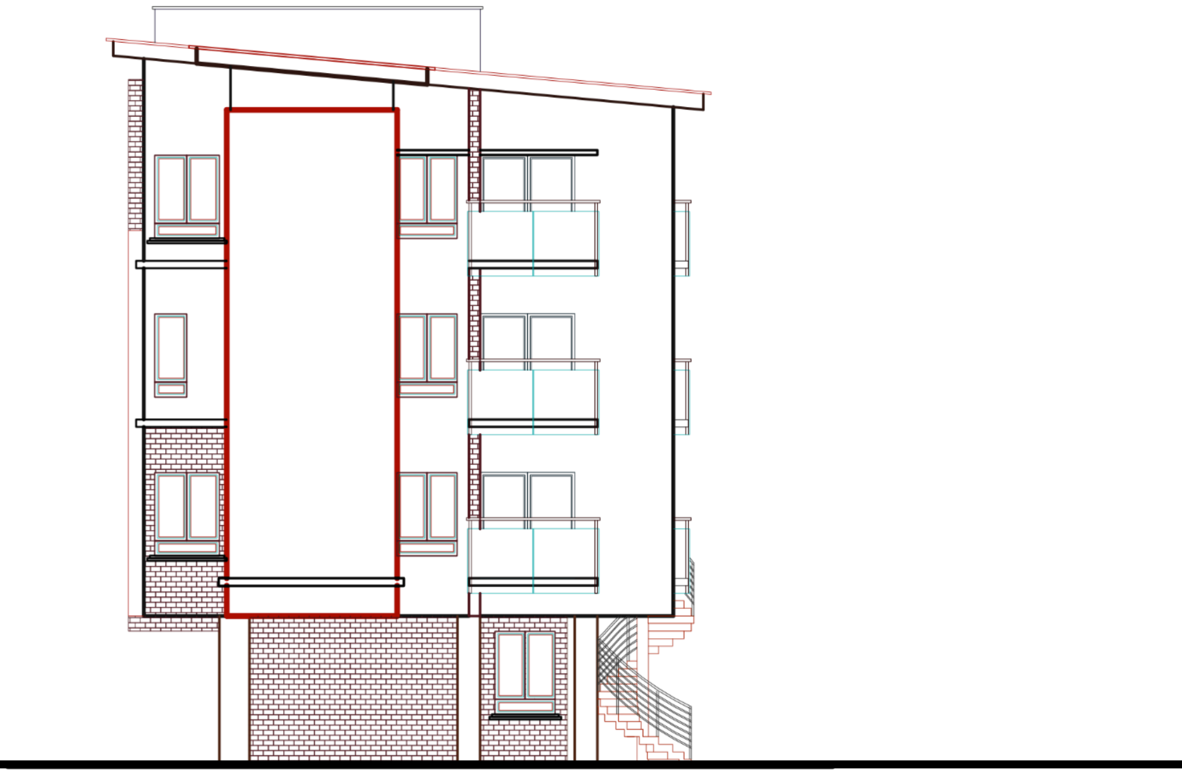


Front Elevation

Left Elevation

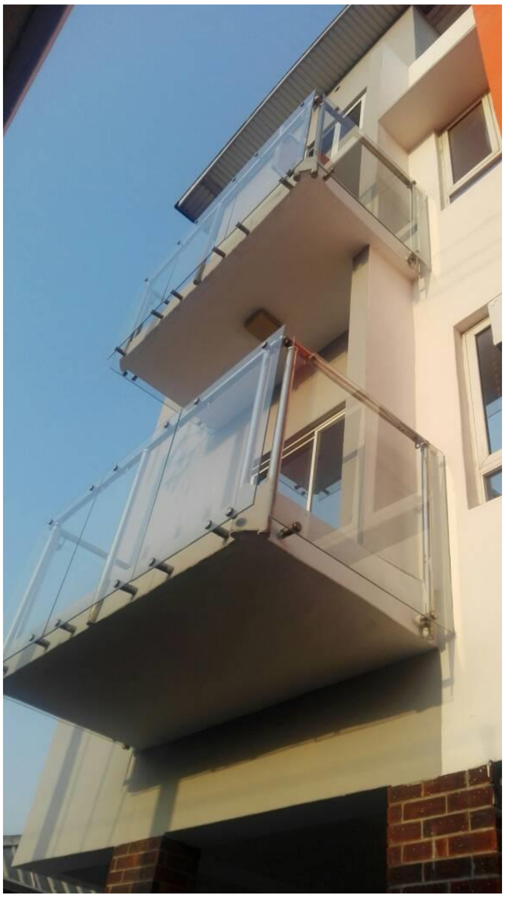
Sheet 4.15	**Elevations** Contemporary block of 5 flats in Yaba, Lagos State	Scale: 1:150 Source: author's study

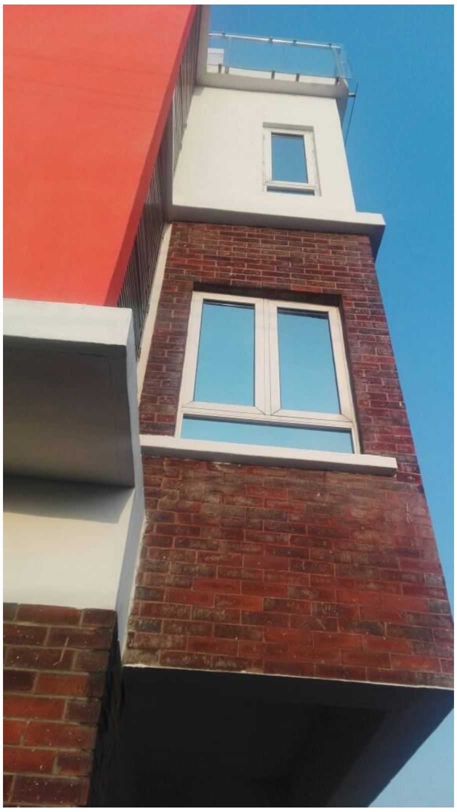
Right Elevation



Rear Elevation

Sheet 4.16	Elevations Contemporary block of 5 flats in Yaba, Lagos State	Scale: 1:150 Source: author's study





Sheet 4.17

Exterior Views

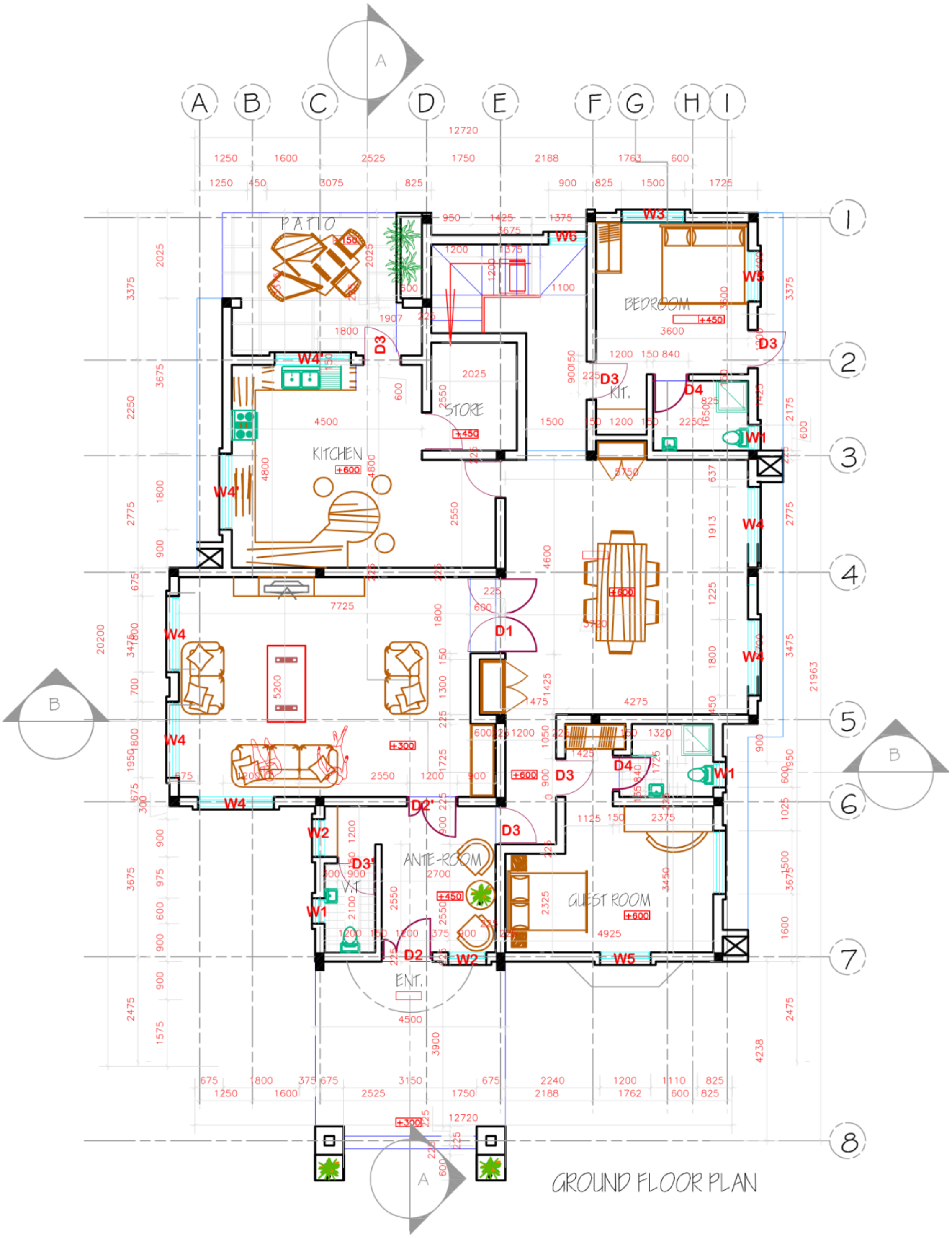
Contemporary block of 5 flats in Yaba, Lagos State

Scale: none

Source: author's study

more diverse cultural and economic backgrounds than at the core and intermediate zones. These are people who have relocated in search of business and educational prospects. Therefore, the houses here show sophisticated contemporary concrete and aluminium construction built to an unfinished degree. Some other types feature cement-plastered mud/cement block walls, timber roof trusses covered in corrugated iron sheets; timber walls (made of wooden planks or bamboo), akin to the illegal settlements on the edges of the planned town. Furthermore, the floor plans of these houses are usually patterned after the early colonial rooming house. Some types possess facades that demonstrate the Brazilian style. However, the floor plans of post-independence and contemporary housing models of higher income brackets are fundamentally patterned after the PWD block of flats and the single detached European bungalow. Therefore, most houses here display a higher quality than those in the core and intermediary zones, in terms of infrastructural supplements, architectural design and specification. However, features such as screen walls, perimeter verandas, stilts, large eaves and interior courtyards associated with the colonial modern types have gradually became uncommon (Prucnal-Ogunsote, 1993). The most common contemporary building envelope in the periphery consists of reinforced concrete structural framing, concrete block wall panels; aluminium framed sliding or casement glass windows; aluminium roofing sheets on timber roof trusses (Aboutorabi, 1985; Ezema, Opoko & Oluwatayo, 2016). However, single detached dwellings possessed the highest percentage of post-independence hosing in Yoruba towns (Adenle, 1969; Tipple, 2000).

According to Adenle (1969), a 1969 field survey of the residential areas in Iwo revealed that of the 5335 dwellings in the city, 4433 (83.1%) were single and detached (bungalow), 704 (13.2%) were semi-detached (two bungalows sharing a common wall) and 198 were terraced (apartment block) (3.7%). Furthermore, 89.6% were one-storey, 10.1% were two-storey and 0.3% were multi-storey. The typical bungalow model consisted of a large distinct anterior space functioning as a sitting and dining area was introduced alongside interior kitchen and bathroom spaces. Adeokun (2013) insinuates that the *akodi* of the traditional compound house-types has evolved into the standard living room which characterises this type. Additionally, the contemporary bungalow typically accommodates 1 household/family on a single plot of land, with an average family size of 3-6 people (Adeniji & Ogundiji, 2009; Okeyinka & Amole, 2012), a lesser number of occupants that that of the rooming and compound houses. Thus, there is more departure from traditional Yoruba family living in the contemporary house than in the vernacular types. The post-independence bungalow became associated with the working- class upper and middle-income dwellers who had adequate resources to build personalised designs (King, 1984). Figures 4.99 and 4.100 show the exterior and interior views of a contemporary bungalow. However, in a case where the family was upper-middle class, they could afford a detached dwelling with more than one floor (typically two);



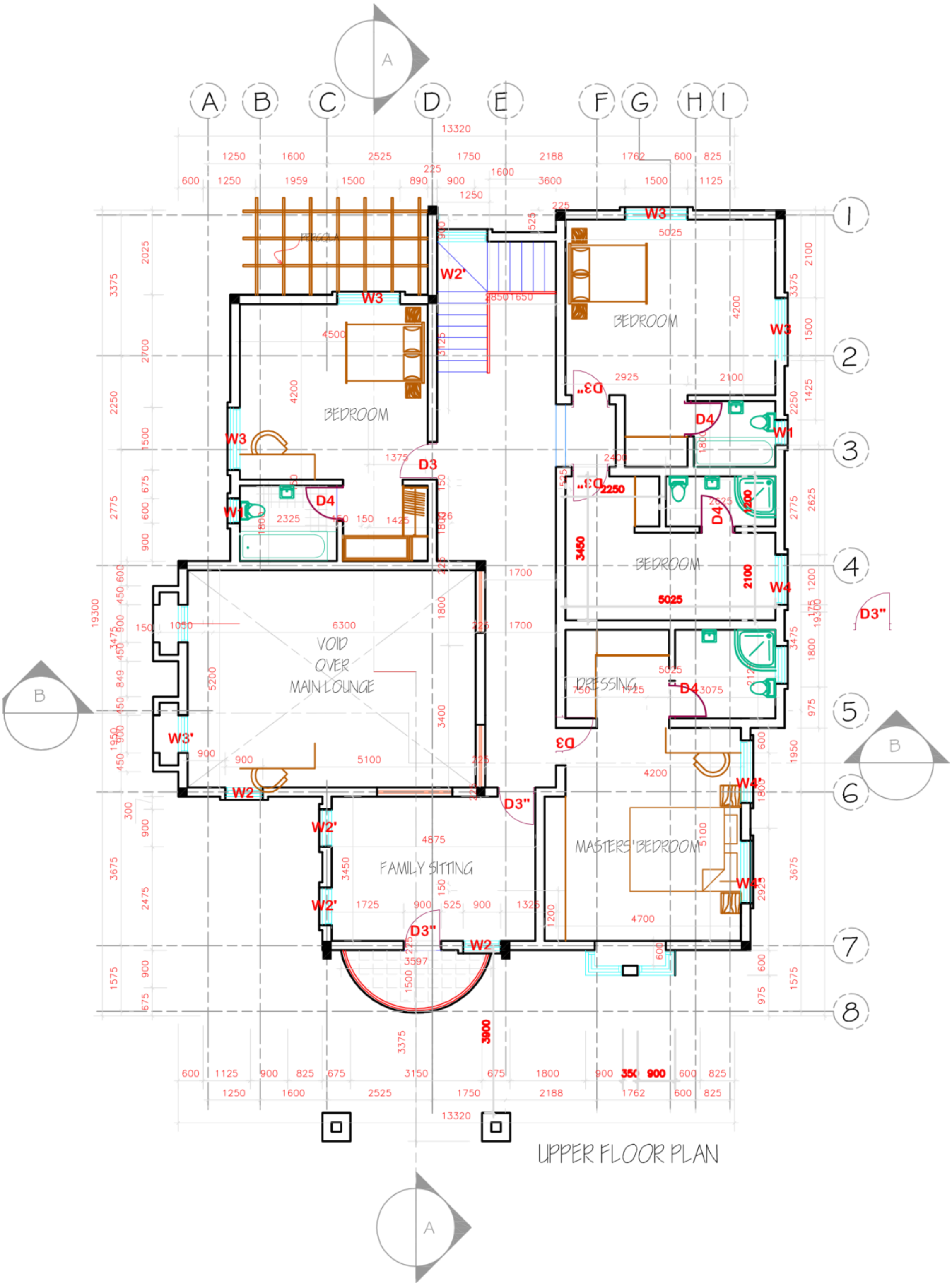
Sheet 4.18

Ground Floor Plan

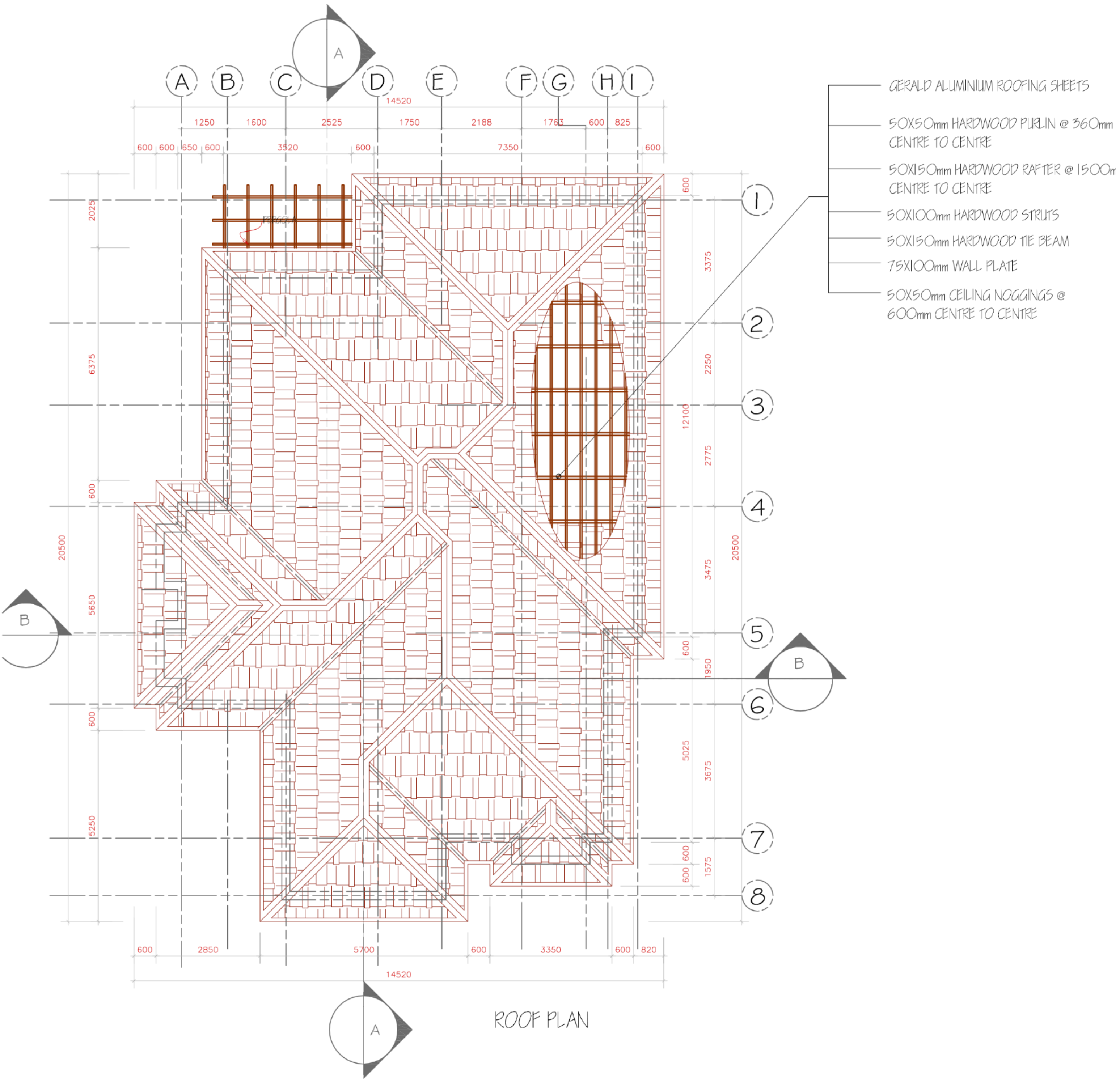
Contemporary 5-bedroom duplex in Abeokuta, Ogun State

Scale: 1:150

Source: author's study



Sheet 4.19	**First Floor Plan** **Contemporary 5-bedroom duplex in Abeokuta, Ogun State**	**Scale: 1:150** **Source: author's study**



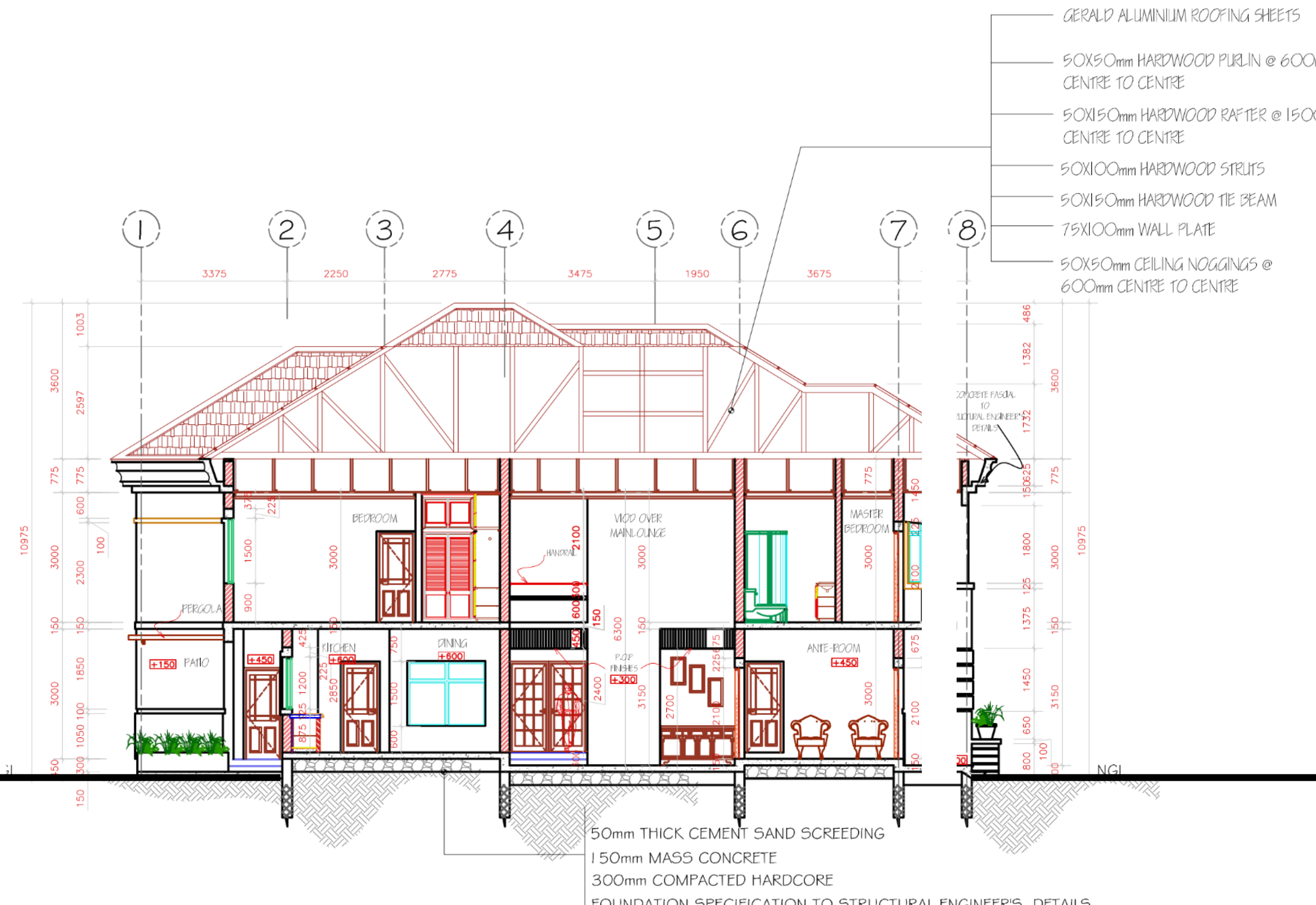
Sheet 4.20

Roof Plan

Contemporary 5-bedroom duplex in Abeokuta, Ogun State

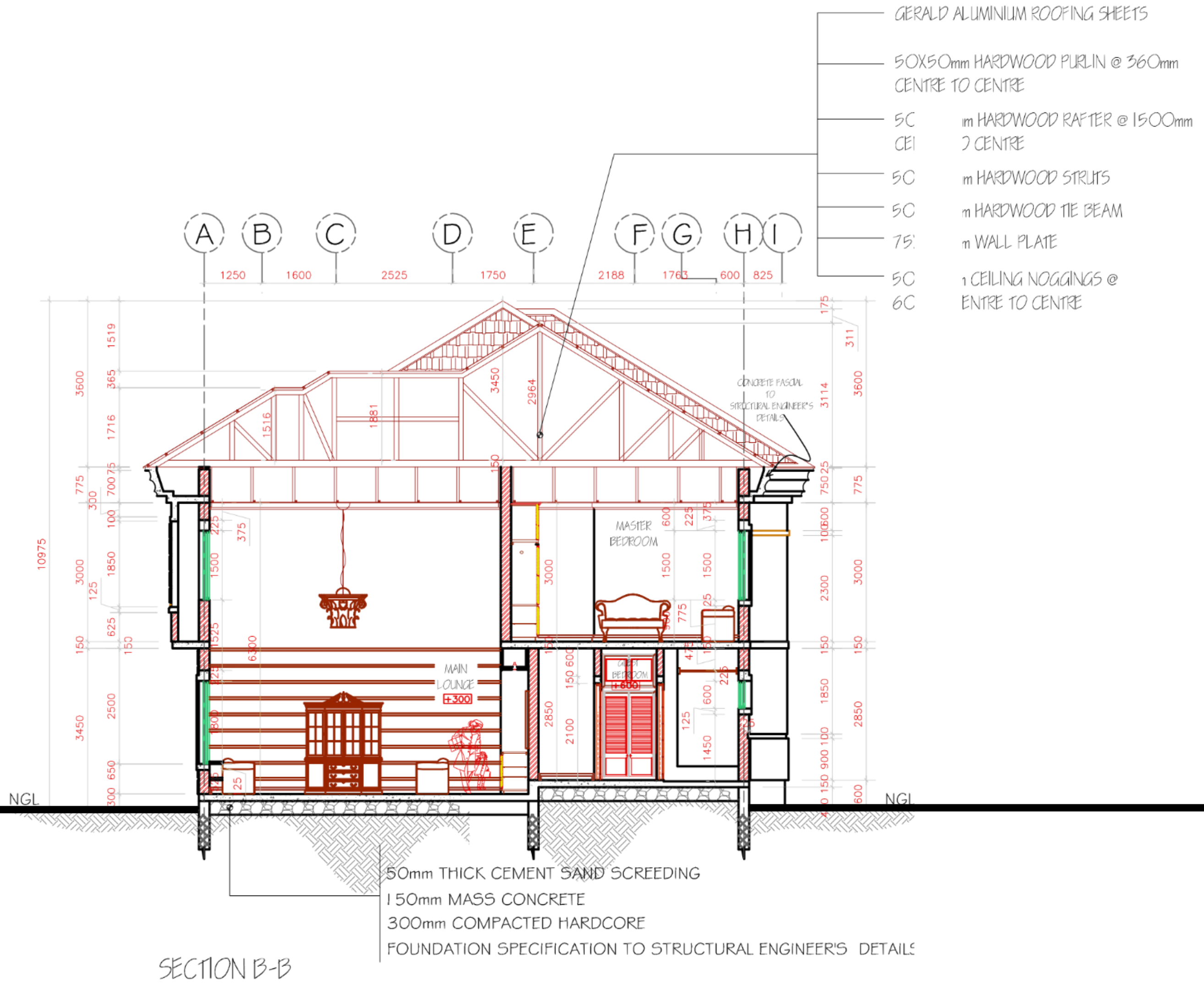
Scale: 1:150

Source: author's study



SECTION A-A

Sheet 4.21	Section A-A Contemporary 5-bedroom duplex in Abeokuta, Ogun State	Scale: 1:150 Source: author's study



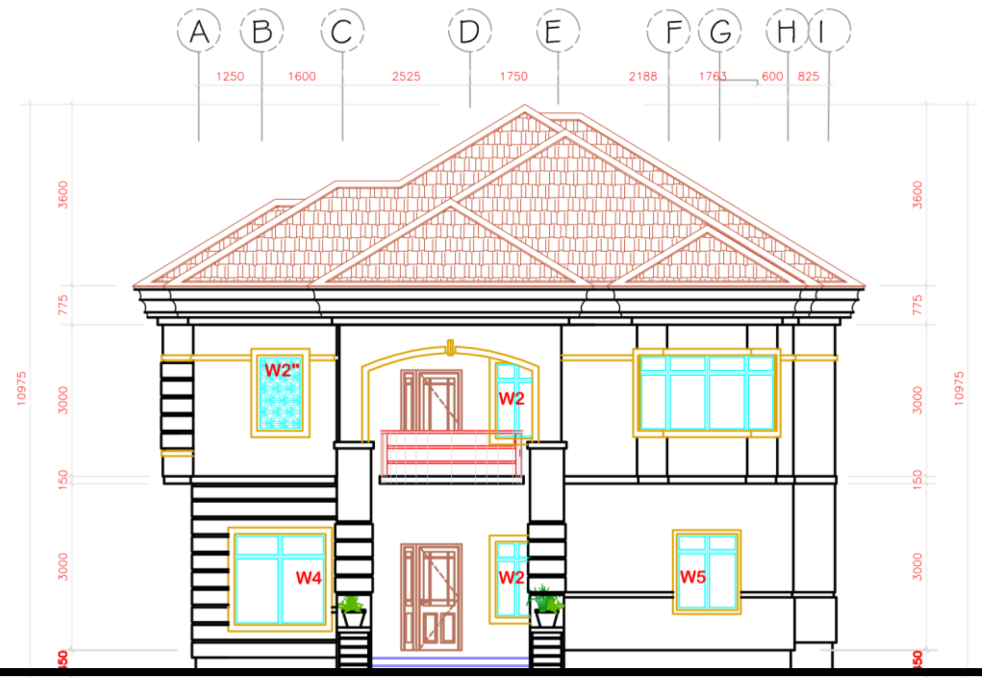
Sheet 4.22

Section B-B

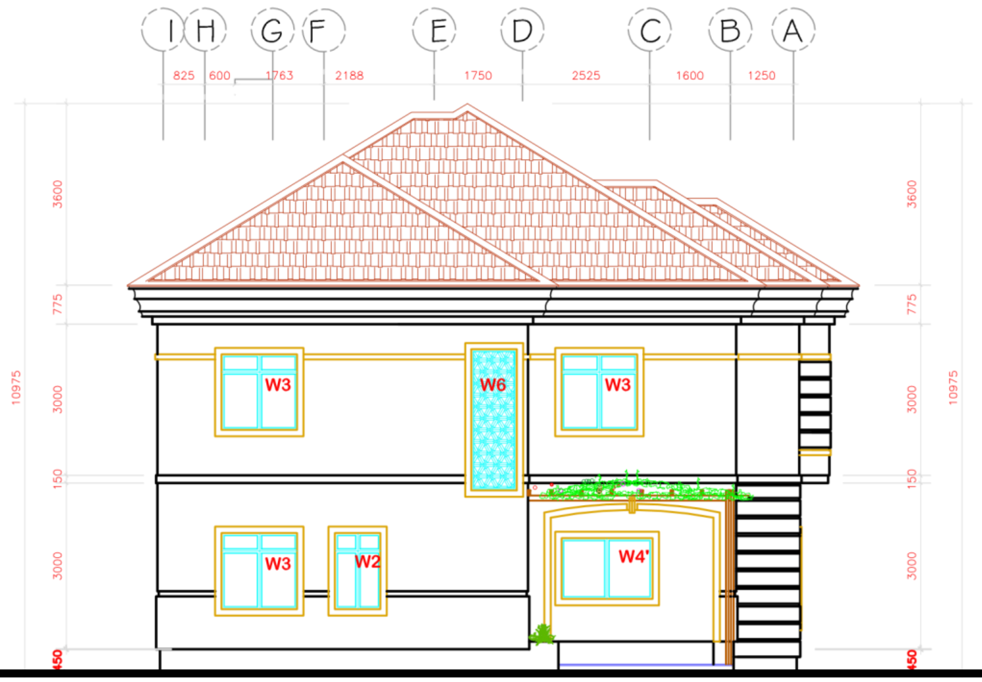
Contemporary 5-bedroom duplex in Abeokuta, Ogun State

Scale: 1:100

Source: author's study

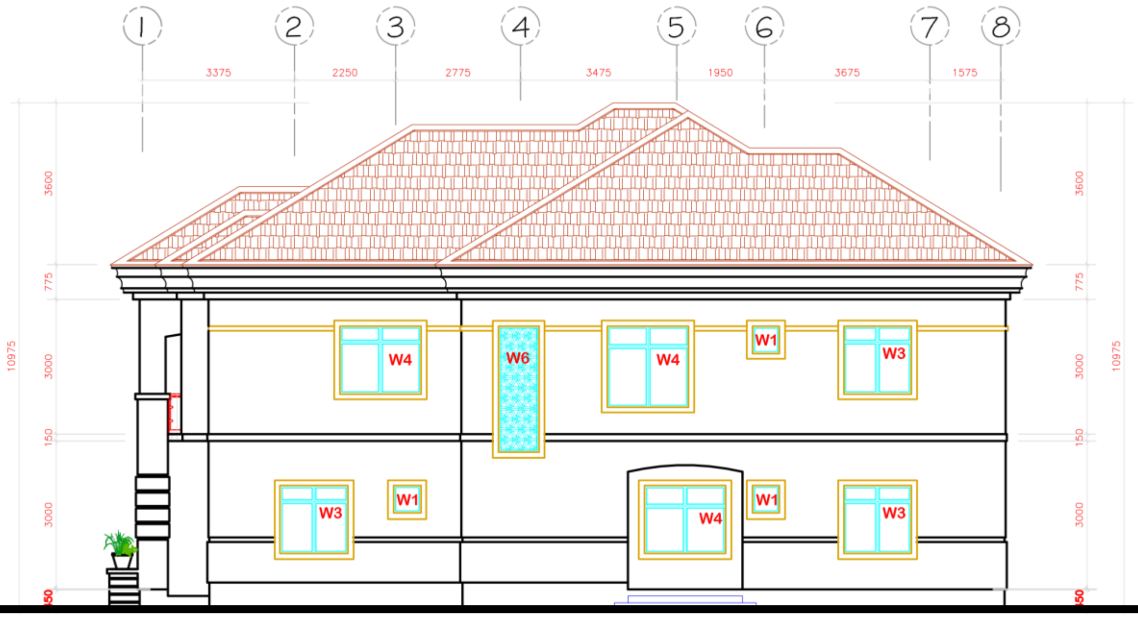


APPROACH ELEVATION

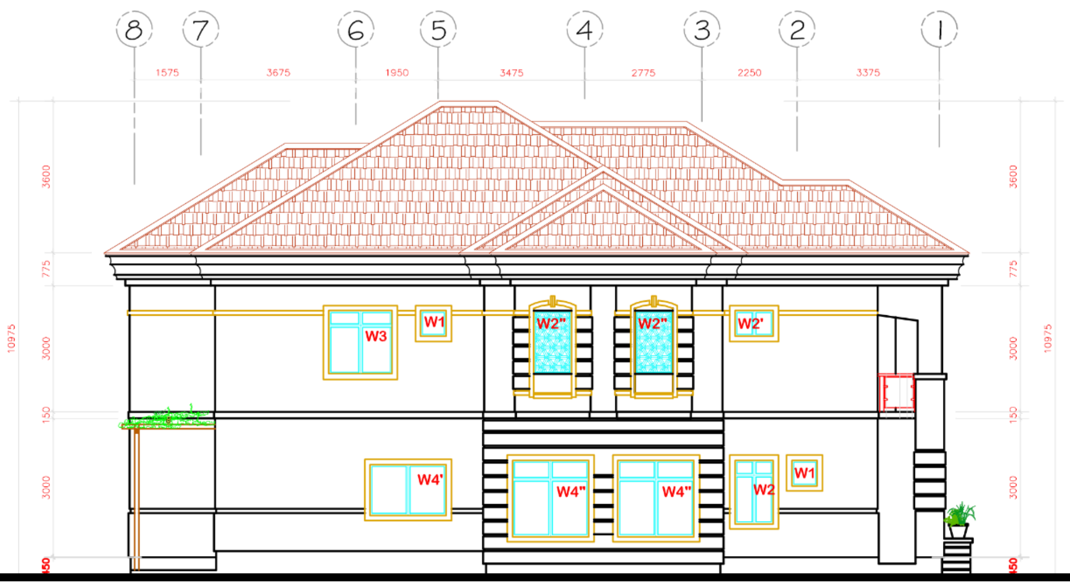


REAR ELEVATION

Sheet 4.23	**Elevations** **Contemporary 5-bedroom duplex in Abeokuta, Ogun State**	**Scale: 1:150** **Source: author's study**

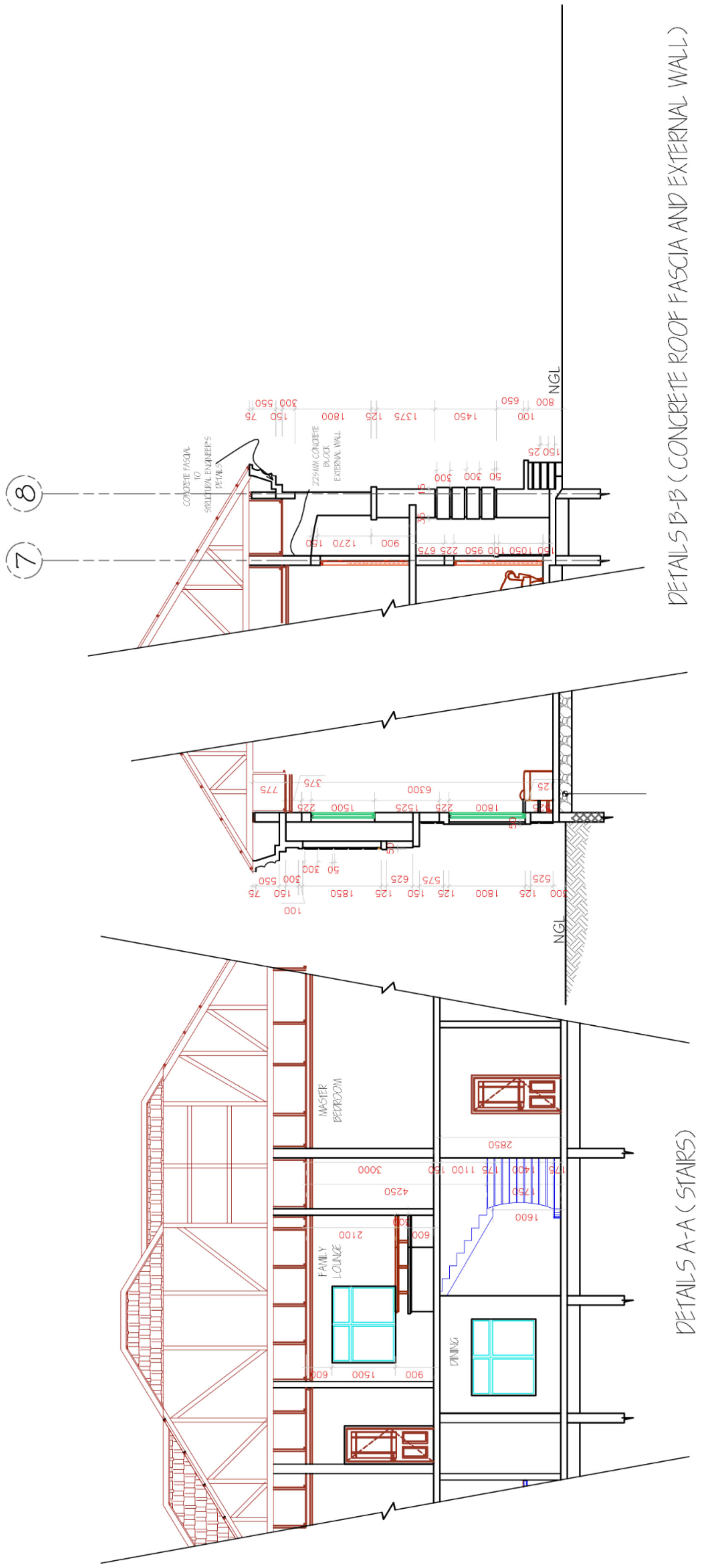


RIGHT ELEVATION



LEFT ELEVATION

Sheet 4.24	**Elevations** **Contemporary 5-bedroom duplex in Abeokuta, Ogun State**	**Scale: 1:150** **Source: author's study**



Sheet 4.25

Construction details

Contemporary 5-bedroom duplex in Abeokuta, Ogun State

Scale: 1:150

Source: author’s study

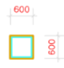
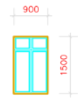
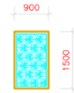
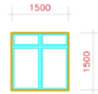
Sheet 4.26

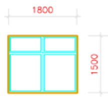
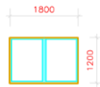
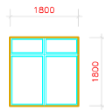
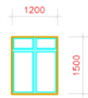
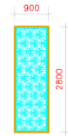
Window Schedule

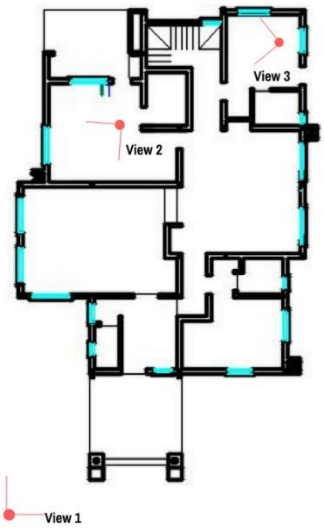
Contemporary 5-bedroom duplex in Abeokuta, Ogun State

Scale: 1:150

Source: author's study

Type	Drawing	Description	NO	Location
W1		colour coated anodized casement aluminium window with 4mm thicktinted glass	5	toilet
W2		colour coated anodized casement aluminium window with 4mm thicktinted glass	4	ante,staircase, master bedroom
W2'		colour coated anodized casement aluminium window with 4mm thicktinted glass	1	master's toilet, box room
W2''		glass block to manufactural details	3	mainlounge
W3		colour coated anodized casement aluminium window with 4mm thicktinted glass	6	bedroom,maidroom, guest bedroom

Type	Drawing	Description	NO	Location
W4		colour coated anodized casement aluminium window with 4mm thicktinted glass	2	family lounge, master bedroom
W4'		colour coated anodized casement aluminium window with 4mm thicktinted glass	2	kitchen
W4''		colour coated anodized casement aluminium window with 4mm thicktinted glass	3	mainlounge
W5		colour coated anodized casement aluminium window with 4mm thicktinted glass	3	guest bedroom, maidroom, master bedroom
W6		glass block to manufactural details	2	stair hall



Sheet 4.27	Exterior and Interior Views Contemporary 5-bedroom duplex in Abeokuta, Ogun State	Scale: none Source: author's study

Figure 4.99 Exterior views (top image shows front view; bottom image shows left side of rear view) of a contemporary five-bedroom bungalow – notice aluminium roofing sheets, concrete block wall and sliding glass windows; source: author's study.

Figure 4.100 Exterior (top image shows left view) and interior (bottom image shows living room looking into dining area) views of a contemporary five-bedroom bungalow – notice air conditioning unit in the wall of the exterior view and electric fan in the interior view, mechanical devices for conditioning the thermal environment; source: author's study.

this is commonly called a duplex (Okeyinka & Amole, 2012) (see sheets 4.18 to 4.27). Contemporary designs feature the rampant use of mechanical cooling in buildings (Akinsemoyin & Vaughan-Richards, 1977) (see sheets 4.9 and 4.17, Figure 4.100). Therefore, buildings were built closer together and orientation of walls and windows became very flexible. Windows became smaller and sun-shading devices were few. The emergence of mechanical cooling in contemporary house-types may be traced to the influence of the International Style (Prucnal-Ogunsote, 1993).

The International Style began before the First World War and was publicised by H.R. Hitchcock and Phillip Johnson around 1932 (Curl, 2006). It is believed to have officially originated in Germany through the work of Walter Gropius among others. Although, the International style is believed to be related to the Modern Movement, the former is regarded as a futuristic style featuring dissymmetry, extreme and cubic shapes with plain surfaces (Ibid; Prucnal-Ogunsote, 1993; Short, 2017). The construction demonstrates extensive use of glass, steel, concrete and reinforced concrete to create largely lightweight building envelopes (Curl, 2006). The style spread all over the world after 1945; it gave mid-late twentieth century architects and continues to afford contemporary architects the freedom to experiment with form (Ibid; Short, 2017). It is a symbol of contemporary advanced living and therefore it was especially embraced in developing countries including Nigeria. However, mechanical thermal control devices are a standard feature of contemporary International style architecture as it has become a universal style replicated in all types of climates (Short, 2017). In the context of south-west Nigeria, the International style was initially used in designing public buildings. The 1983 First Bank Headquarters in Lagos and 1985 IMB Building in Victoria Island Lagos were the first steel and glass buildings in the region (Oyedele, 2016). These commercial buildings indicated advanced urban living and gradually the International Style began to reflect in domestic buildings whose owners and occupants desired advanced urban living. The typical building envelope for south-west Nigerian post-independence detached dwellings especially in current times, include plastered concrete block walls, concrete flooring and roof of reinforced concrete slab/galvanised iron sheets or slates in steel/timber trusses (Adenle, 1969). As new builds continue in response to urbanisation, this contemporary/post-independence envelope has become the template for construction (Jiboye & Ogunshakin, 2010).

According to the historical, socio-economic and cultural changes over time, it seems logical that south-west Nigerian housing be classified into three broad categories: traditional, colonial and post-independence/contemporary. However, certain studies suggest that there are no clear classifications among house-types in south-west Nigerian cities because older and newer models coexist in contemporary times. Jiboye & Ogunshakin (2010, p.123) state that in Oyo town, "...*the effects of urbanization on the city have not created much contradictions between the "old and the new" cultures* *which mutually coexist in the area of housing and socio-economic intercourses…*" Furthermore, other authors have classified types across different periods under one category. Yetunderonke (2015) classifies the indigenous compound house-type and early colonial rooming houses as traditional house-forms in contemporary Yoruba cities. Oyedele (2016) classifies houses of sandcrete and concrete as traditional. Yet others attempt to relate house-types across the different periods. Adeokun (2013) states that the *Orowa* house and contemporary house types in the region bear space use similarities which embody the culture of the indigenes. The question here is: are there clear definitions among south-west Nigerian house-types based on historical and cultural changes over time?

4.4 Defining the styles of south-west Nigerian house-types based on historical and cultural changes over time

In attempting to define the styles of south-west Nigerian house-types, it appears best to analyse the dominant domestic architecture created within each chronological period, and its cultural representations. The literature has shown that the indigenous people of south-west Nigeria had their own form of architecture prior to any external influences. This architecture is traditional or indigenous to south-west Nigeria. In contemporary times, traditional architecture is seen as a symbol of underdevelopment and backward thinking (Lloyd, Mabogunje & Awe, 1967; King, 1984). This perspective seems very myopic. The literature has shown that the traditional architecture of south-west Nigeria was the physical representation of an organised society. The 'mud huts' came out of the very organised and clear socio-cultural principles and values, which were handed down through generations (Denyer, 1978). There was a deliberateness in the way the traditional compound was laid out, with the external wall a symbol of protection and separating a unique part (the lineage) of a whole (the village). The indigenous Yoruba understood the importance of community. Each lineage lived according to cultural norms and there was little variation among the house-types. Traditional south-west Nigerian housing is defined as an expression of the strong and organised social structure of the indigenous Yoruba. However, the original physical models of the traditional Yoruba culture seem to be lost due to historical changes.

There are studies (Oyedele, 2016; Salami, 2016) which suggest a clear demarcation between traditional traditional and colonial house-types. However, Prucnal-Ogunsote (1993), Adeokun (2013) and Oyedele (2016) have identified a south-west Nigerian architecture termed vernacular which was demonstrated in indigenous types showing similarities to Brazilian architecture. The vernacular types include the palaces of the kings and chiefs with cement-plastered mud walls and roofed in iron, the Brazilian style palaces (the Ife-type *afin* at Ikere, the Lagos *afin*) and houses. Authors such as Mabogunje (1971), Fourchard

(2003), Immerwahr (2007) have classed the disintegrated traditional compounds as informal settlements because the occupants refused European town planning. However, it appears that this classification is based on the quality of life and infrastructure, not socio-cultural significance. This study suggests that the disintegrated compounds are vernacular because they were modified with some features shared by Afro-Brazilian architecture. The Afro-Brazilian houses were associated with wealthy merchants in the colonial period. Consequently, these houses appeared desirable and the replication of some of their features in the traditional compound houses was facilitated. These features manifested themselves as cement-plastered mud/cement block walls and corrugated iron roofs. This study offers that the disintegrated compound houses be termed vernacular alongside the Brazilian style housing. It suggests that south-west Nigerian vernacular housing represented transition from traditional to modern as well. The vernacular house-type was not just a result of the merging of traditional Yoruba styles with traditional European and south-American influences. It signified the openness of the culture to others, the ability of Yoruba and their architecture to adapt to and learn from external influences. Lloyd, Mabogunje & Awe (19670 class the Brazilian houses as semi-modern. However, the Portuguese and Brazilian influences were not modern but traditional to their original locations (Vlach, 1984; Fernandes, Mateus, Braganca & Correia da Silva, 2015). These styles bore a different aesthetic and structural sophistication from the Yoruba traditional architecture. It was here that the ability of the Yoruba to express their tradition through borrowed styles began. A strong indication of this fact is the communal living element common to the traditional and the vernacular types, which was carried on from the traditional to the vernacular. This suggests why authors such as Oyedele (2016) classify both as traditional. However, this study suggests that the south-west Nigerian vernacular housing has other values which separate it from the traditional. The vernacular represented a culture in transition, still maintaining original norms, yet learning and evolving. It is an architecture still south-west Nigerian but enriched by foreign traditional styles.

It has been stated that the early colonial British housing belong to the vernacular south-west Nigerian style (Prucnal-Ogunsote, 1993; Adedokun, 2014b; Oyedele, 2016). However, this study proposes that the early residencies of the British colonisers were not vernacular. The colonisers introduced their culture and architectural standards into the south-west Nigerian settings but initially expressed these in south-west Nigerian indigenous construction (Home, 1997). The Western societal structure was based on the nuclear family unit: a man and his immediate family (King, 1984). This lifestyle was seen as indicating education and enlightenment and therefore termed 'modern European culture' (Ibid; Collins & Taylor, 2008). Therefore, the houses they built served a major occupant (usually an official or missionary) and a few others (a wife or mission partners). The early British dwellings, such as the timber-thatch bungalows and mission houses, were detached and built to accommodate and meet the individual needs and preferences of officials and missionaries with a few other occupants. Secondly, the colonisers brought in their own design and building standards developed in their modern society to meet housing needs in the Yoruba region. The layout of the timber barrack accommodation and the imported envelopes of the Georgian Style houses exemplify this. Accordingly, this study proposes that the earliest colonial European settlements be classified as semi-modern. They were the interpretations of the modern European culture using south-west Nigerian construction. Semi-modern south-west Nigerian architecture symbolised the initial attempts of European culture to immerse itself in the south-west Nigerian setting. Like the vernacular types, they demonstrated the transition from traditional to modern.

The entrance of the PWD created a new category of housing in the region. Authors such as Lloyd, Mabogunje & Awe (1967), Jackson & Holland (2014), Salami (2016) have identified south-west Nigerian PWD housing and the tropical modernist designs by Fry and Drew as modern. Foreign materials such as reinforced concrete, steel, cement, corrugated iron became dominant resulting in sturdy geometric forms associated with the Modern Movement (Jackson & Holland, 2014). This study supports the fact that the PWD and tropical modernist housing is modern for the following reasons. First, the PWD created housing more suited to modern European living in the south-west Nigerian environment. Foreign materials such as concrete and glass, became more common. Urban planning policies ensured that housing was built and planned in an orderly way and by stipulated standards. However, the features of PWD housing were tailored to the south-west Nigerian climate (King, 1984; Ibid; Jackson & Uduku, 2016; Salami, 2016). It appears that the PWD laid the foundation for other modernist housing in the region such as the LEDB's low-cost housing schemes and the housing of Fry and Drew. Second, the literature has shown that towards the late 1930s, 1940s and Fry and Drew combined the PWD building codes, their modernist principles and Yoruba-inspired forms to produce their own brand of modern architecture: tropical modernism. Tropical modernist house-forms set the trail for innovation and experimentation in modern south-west housing design of the late colonial period. As political power transferred to Nigerians in the 1950s and 1960s, affluent indigenes were able to afford modern houses with innovative and embellished tropical modern design which has been identified as Nouveau Rich architecture. Moreover, the new south-west Nigerian upper-class acquired the modern housing of the Reservations and more modern housing (GRAs and elite estates) were built for the new empowered and educated indigenes. Accordingly, south-west Nigerian modern housing seems to represent the introduction of a different lifestyle associated with enlightenment and education which upper and middle-income south-west Nigerians strove to acquire and make their own. It represents a refinement of the south-west Nigerian culture due to learning from Western education and culture.

The literature has shown that, post-independence, urban planning standards established during the colonial period fell short. As such it appears that individuals exercised more freedom towards the kind of housing they wanted. Still post-independence houses continued to be patterned after modern types, especially in the immediate post-independence years (the 1960s to 1980s). Post-independence housing was created after independence amongst existing traditional, vernacular and modern types. However, western culture had already been set, since colonial times, as the highest standard of living; the indigenous upper-class refined their lifestyles in accordance with European trends (King, 1984; Prucnal-Ogunsote, 1993; Jiboye & Ogunshakin, 2010; Lawal & Ojo, 2011). Thus the upper-class defined a standard of living desired by the majority of south-west Nigerians (Lloyd, Mabogunje & Awe, 1967). When the International Style became popular in the region 1980s, it influenced Nouveau Rich housing and gradually the masses' housing. The resulting cuboidal, concrete and steel structures have been termed contemporary (Prucnal-Ogunsote, 1993; Jiboye & Ogunshakin, 2010; Lawal & Ojo, 2011; Short, 2017). It seems that cuboidal housing forms with concrete and glass building envelopes existed since the colonial era. Authors such as Prucnal-Ogunsote (1993) suggest that in the south-west Nigerian context, the International Style is a form of the Modern Movement. Prucnal-Ogunsote's 1993 study classes International Style Nigerian architecture under the Modern Style. However, this study proposes that though both styles are related as they both feature similar building technologies and aesthetic values, there is a distinct difference between both. While the modern style considered local culture and climate, the International Style did not. The International Style houses were built by south-west Nigerians who desired the advanced contemporary urban culture, expressed through concrete, steel and glass houses with artificially controlled internal environments. Accordingly, this study agrees with studies such as King (1984), Prucnal-Ogunsote (1993), Jiboye & Ogunshakin, (2010) and Lawal & Ojo (2011) that contemporary south-west Nigerian housing is a result of a departure from refining their own culture with Western education to a blind replication of the latter. This departure was driven by the desire for wealth accumulation and peak social status. This study offers that the modern style and contemporary style are two different styles of housing in the south-west Nigeria.

So far, this study has identified five styles of south-west Nigerian housing based on historical and cultural changes: traditional, vernacular, semi-modern, modern and contemporary. However, there is one more type of south-west Nigerian housing whose style seems undefined: the informal settlements. Earlier on, three types of informal settlements were mentioned: the disintegrated traditional compound housing, the illegal settlements at the edges of the intermediate zones and the peripheral unplanned settlements. These housing areas have been termed informal based on the definition: heavily populated areas with substandard buildings which show disorder in planning and layout, no secure/legal tenure and antisocial

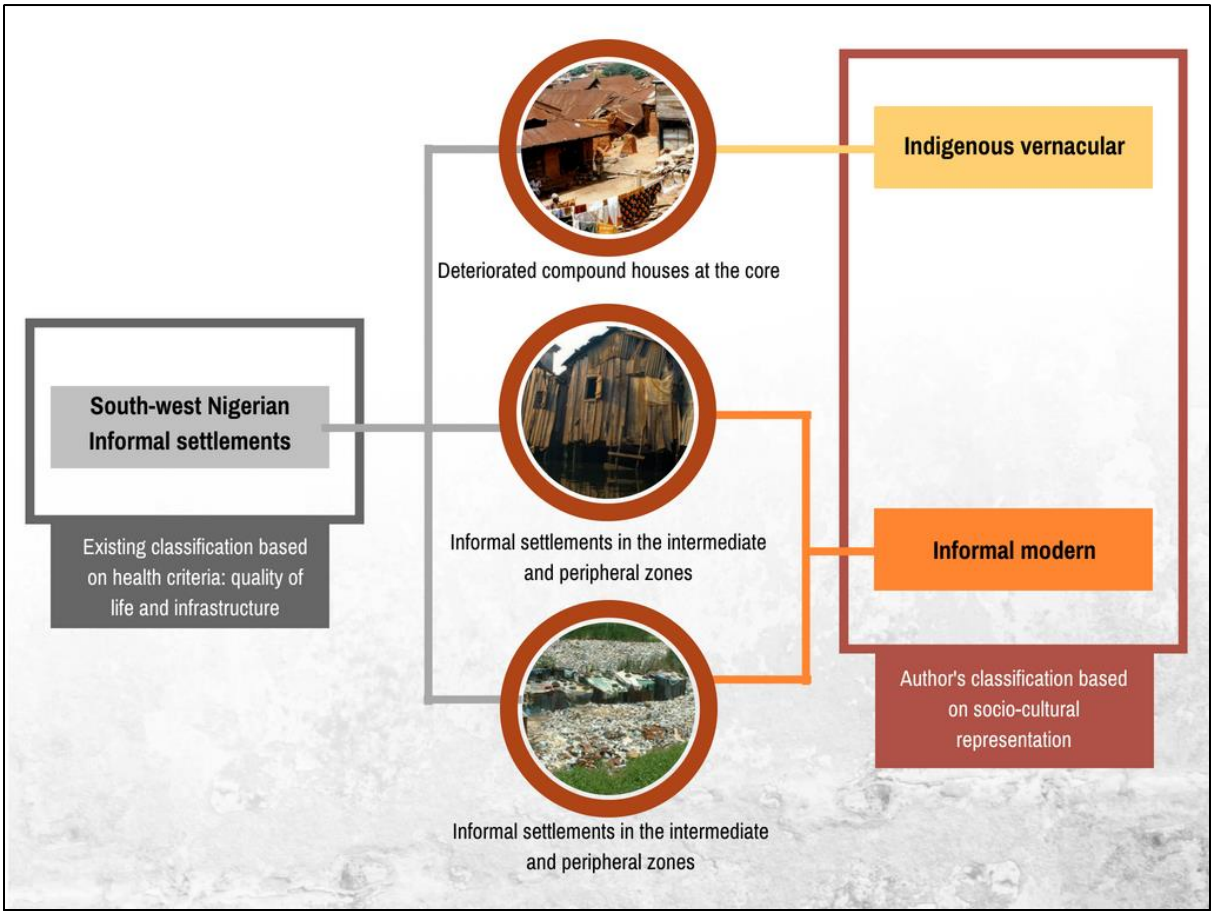


Figure 4.101 Author's socio-cultural classifications of informal settlements, which have been so labelled due to health criteria; source: author's study.

activities (Simon, Adegoke & Adewale, 2013). Furthermore, informal settlements have been described as featuring overcrowding, refuse heaps, inadequate supply or lack of safe water, electricity, hygiene and access to medical amenities (Fourchard, 2003; Immerwahr, 2007). Accordingly, it seems that the term 'informal settlement' is used to classify the neighbourhood and corresponding housing based on quality of life, architecture and infrastructural planning. These criteria may be said to coincide with the non-physical housing aspect of health, discussed in Chapter 2. Still in terms of the non-physical housing dimension of culture and social values (likewise discussed in Chapter 2), it appears that the socio-cultural representations of south-west Nigerian informal settlements are not clearly defined. Thus, based on cultural representation, this study has suggested that the disintegrated compound areas be classed as vernacular (see Figure 4.101).

The second and third groups of informal settlements are the illegal types of the intermediate zones and peripheral unplanned types. The literature has shown that the housing in these settlements feature a diverse range of construction. Moreover, these informal settlements were created by people from diverse ethnic groups who moved to major south-west Nigerian cities in search of employment opportunities. Those who were unsuccessful at securing employment which could have propelled them to higher income

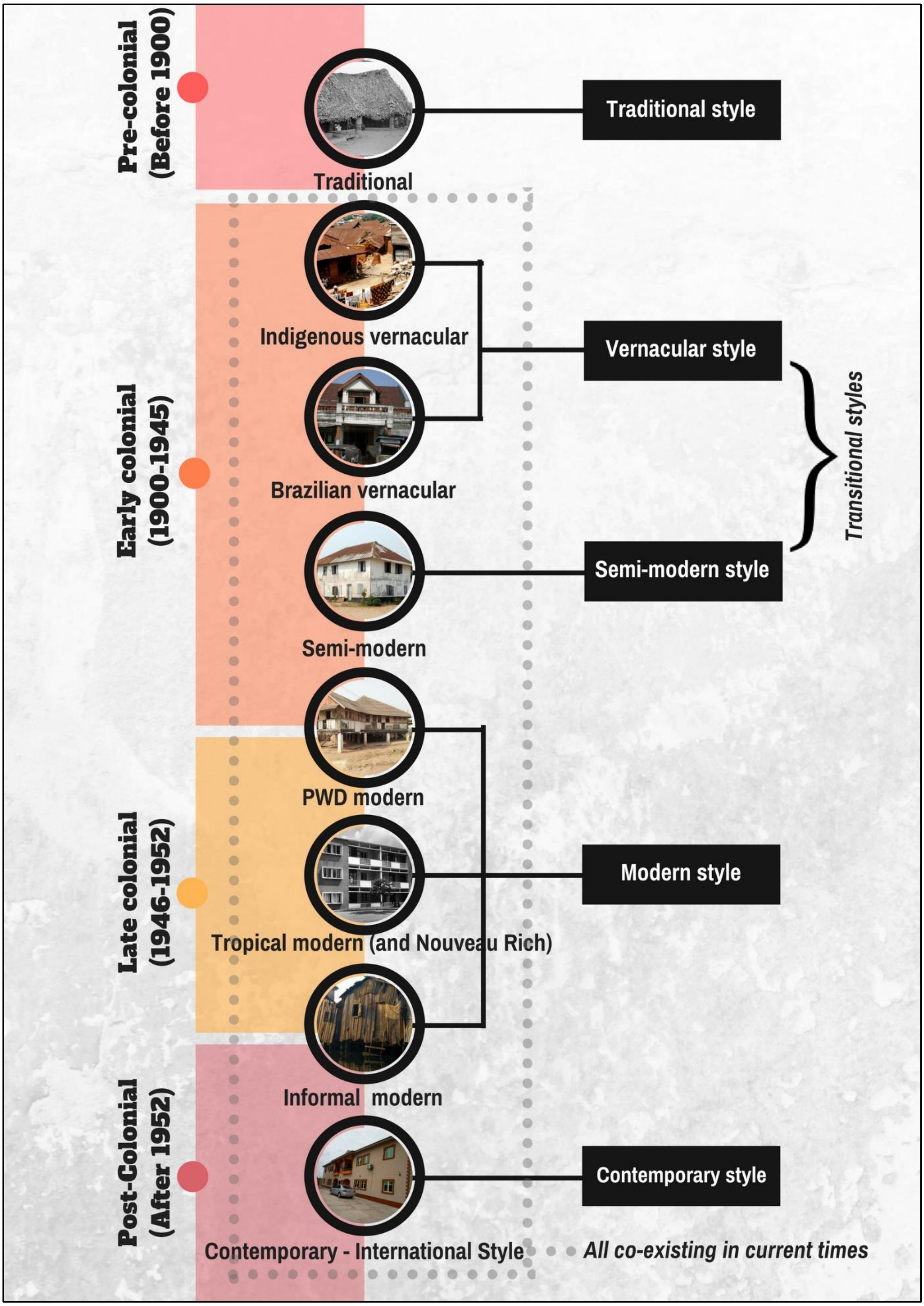


Figure 4.102 Author's chronological classification of south-west Nigerian housing based on cultural connotation; source: author's study.

levels resorted to creating housing they could afford. This rural-urban migration began in the mid-late colonial period when there was a huge amount of economic growth in the region. This study suggests that the emergence of these informal (illegal and unplanned) settlements represented a failed striving for the Western lifestyle which had been embraced and adapted by the new indigenous upper- and middle-income class. Therefore, this study proposes that based on its cultural significance, the illegal and unplanned informal settlements be classed as modern. This deduction is in line with Olayemi's (1980) study which calls the migrant settlements 'modern'. The illegal informal settlements of the intermediate zones and the peripheral unplanned informal settlements are south-west Nigerian modern housing of the low-income class (see Figure 4.101).

This study has attempted to demonstrate that there are clearly defined styles among the south-west Nigerian house-types based on socio-cultural significance (see Figure 4.102). The fact that housing from different periods still coexist in contemporary times does not change the socio-cultural definitions of each category and what it represents. In Chapter 3, space cooling and energy consumption were established as the main factor in the relationship between south-west Nigerian housing and climate change. However, as south-west Nigerian housing has been explored in more detail, it seems necessary to analyse the climate-responsiveness of each housing category and its relationship to climate change.

4.5 Climate-responsiveness and climate adaptation across the contemporary south-west Nigerian building envelopes

In the previous chapter, climate-responsive architecture was defined as architecture which takes advantage of climatic features to create thermally comfortable built environments with minimum contributions to climate change. Therefore, climate-responsive architecture seems a potent strategy in combating the present issue of climate change. The previous chapter has established that south-west Nigeria is experiencing climate change and the residential sector is a contributor. This implies that there is a low level of climate-responsiveness in south-west Nigerian housing but is this factual, especially for all the identified classes of housing? Based on the qualitative climatic design principles discussed in Chapter 2 and the types of climate adaptation outlined in Chapter 3, this study will attempt to identify and analyse, the climate-responsive features of the different south-west Nigerian housing categories. It intends to ascertain which house envelope is most significant regarding contemporary south-west Nigerian climate change.

Earlier on, the Yoruba indigenous housing envelope was described as built of locally sourced, inexpensive materials: adobe, grass fibres and timber (Osasona, 2007a; Adedokun, 2014b). These materials have been proven to be well suited to the contextual climatic conditions (Itajuyi and Taiwo, 2012). In current terms, these traditional materials relatively possess minimum embodied energy, creating housing that is low-carbon, a standard that is strived for currently (UNEP, 2009; Bribian, Capilla & Uson, 2011; Onyegiri & Ugochukwu, 2016). Hence, there seem to be no carbon-based climate-change agents in south-west Nigerian traditional construction. Prucnal-Ogunsote (1993) affirms that the climate, human physiology and geography contributed to the development of thatch-roofed and mud-walled houses of the region.

Table 4.1 Table showing the environmental impact of building materials across south-west Nigerian envelopes

Building Material	Primary energy Demand (MJ-Eq/kg)	Global Warming Potential (kg CO_2-Eq/kg)
Brick (soil-based)	3.592	0.271
Cement	4.235	0.819
Reinforced concrete	1.802	0.179
Concrete	1.105	0.137
Aluminium	136.803	8.571
Glass	15.511	1.136
Reinforcing Steel	24.336	1.526

Source: Bribian, Capilla & Uson (2011)

This study agrees with King (1984) that the thermal mass of the external walls helped to control the transfer of heat from the outside to the inside. Thus, less heat was radiated inside, than was absorbed from the outside. The fluted walls of the Bini-inspired courtyard houses fostered a good thermal performance of the wall. The top edge of each flute shaded its lower part reducing the surface area of the wall directly exposed to sunlight (Dmochowski, 1990). The ribbed surface facilitated radiation of the heat absorbed during the day, at night. The thatch roofs acted as insulation and did not absorb heat from the sun; the extended roof eaves over verandas, shaded exterior walls. The mud floors must have absorbed any heat which got into the house and radiated it into the ground by thermal mass. This study agrees with Adedokun (2014b) about the value of the veranda as a contributor to the generous admittance of light and air from the courtyard into the sleeping rooms. Furthermore, Immerwahr (2007) and Adedokun (2014b) insinuate that the small size of the *oju'le* with no windows was a response to climate as the aim was to keep out as much solar radiation as possible. As the focus is the envelope's climate-responsiveness, this study agrees that the presence of few, small or no windows would have greatly reduced solar radiation transmitted through the walls. Still, the reference to the size of the rooms appears like a spatial response to the climate. Szokolay (2014) explains that, optimally, the least surface area be exposed to solar radiation. Nevertheless, natural daylight and ventilation were admitted into the house through the

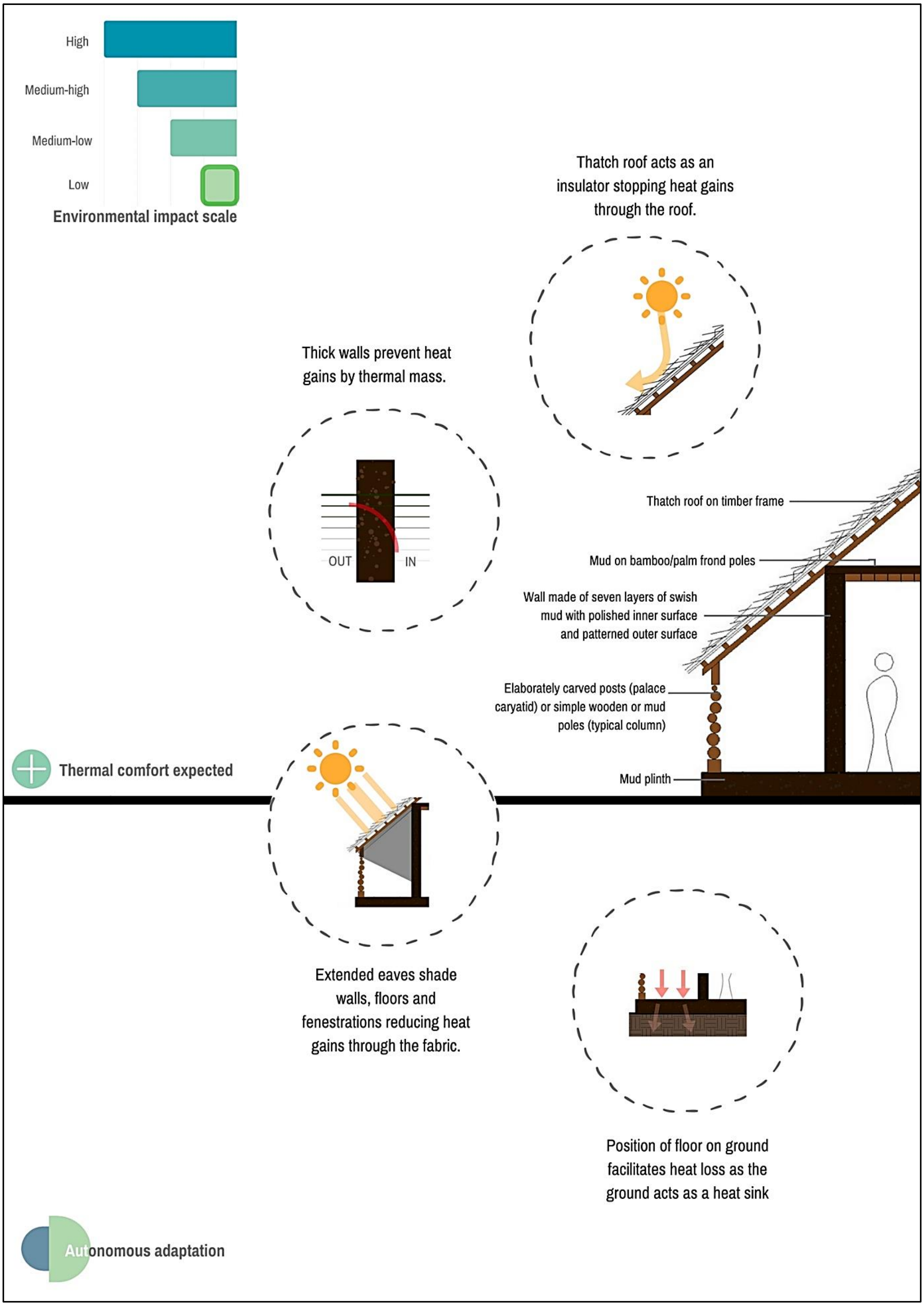


Figure 4.103 Section through traditional house envelope showing climate-responsive features; source: author's study - section based on Akinsemoyin & Vaughan-Richards (1977).

courtyard. The courtyard was primarily created for domestic life rather than climatic consideration (Yetunderonke, 2015). However, the courtyard was "*an essential component for environmental control and socio-cultural changes*" (Osasona, 2007a, p.4). The courtyard appears as a spatial response to the climate as well. Nevertheless, this indicates that there was no conscious effort to embed climatic responses in this type. It appears that the traditional house envelope possesses features which took advantage of the climate (see Figure 4.103). This perspective is supported by previous research which include subjective responses that thermal comfort was achieved within the interior spaces. As its features were developed with intuitive experience rather than formal analysis and deductions (Denyer, 1978; Dmochowski, 1990), the traditional envelope appears to offer the autonomous/spontaneous kind of adaptation to the south-west Nigerian climate (see Figure 4.103).

As stated earlier, the vernacular house envelopes are of two types: indigenous vernacular and Brazilian (including Afro-Brazilian sub-type) vernacular. The indigenous building envelope experienced modifications which created the indigenous vernacular types. The indigenous vernacular envelopes consisted of cement-plastered mud/cement walls and floors, larger windows and corrugated iron sheets on timber trusses. It appears that while the advantage of thermal mass is preserved through the solid walls, the replacement of thatch roofs with corrugated iron indicates more absorption of solar radiation through the roof during the day. Yet these roofs tend to cool down quickly at night. Larger windows indicate more ventilation; however, this may be defeated by the cramped layout of the indigenous vernacular types (Szokolay, 2014). Nevertheless, any heat gains through the roof may be dispelled by ventilation and heat losses through the floor. This seems to indicate thermal comfort. As the indigenous vernacular envelopes are slightly modified versions of the traditional envelope, the basic intrinsic adaptations (thermal mass principles) to the climate remain (see Figure 4.104). Hence, the south-west Nigerian vernacular envelopes demonstrate autonomous adaptation (see Figure 4.104). Still they present a higher threat to the environment than the traditional envelope, with the low-medium primary energy demand and global warming potential. Differently, the Brazilian house envelope ps sturdy, made of white-washed brick walls and plastered in cement or stucco; large timber casement windows, timber/cement flooring and corrugated iron roof. The walls of the Brazilian type indicate thermal mass, which is a beneficial climate-responsive feature. The increased size of the windows suggest good ventilation, which facilitates cooling. However, the choice of corrugated iron for the roof seems to be disadvantageous as the metal has a high conductivity and heats up quickly (King, 1984; Szokolay, 2014). Therefore, substantial amounts of heat are absorbed during the daytime, making interiors uncomfortable. Nevertheless, the large windows of the Brazilian envelope suggest good ventilation and cooling. This study's qualitative assessment of positive indoor thermal comfort in the Brazilian house is in line with Lawal & Ojo's (2011) quantitative study of

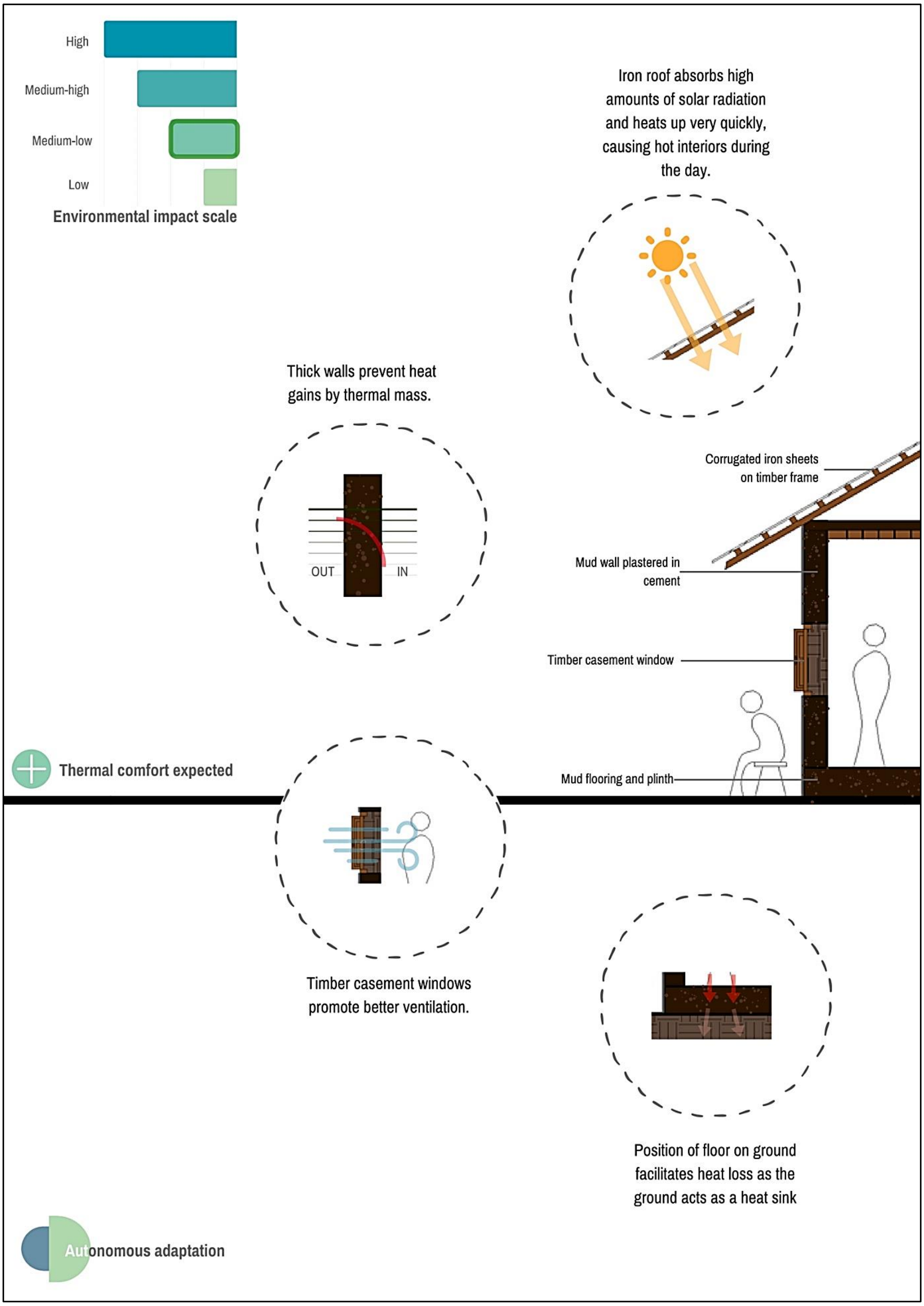


Figure 4.104 Section through indigenous vernacular house envelope showing climate-responsive features; source: author's study - section based on Fourchard (2003).

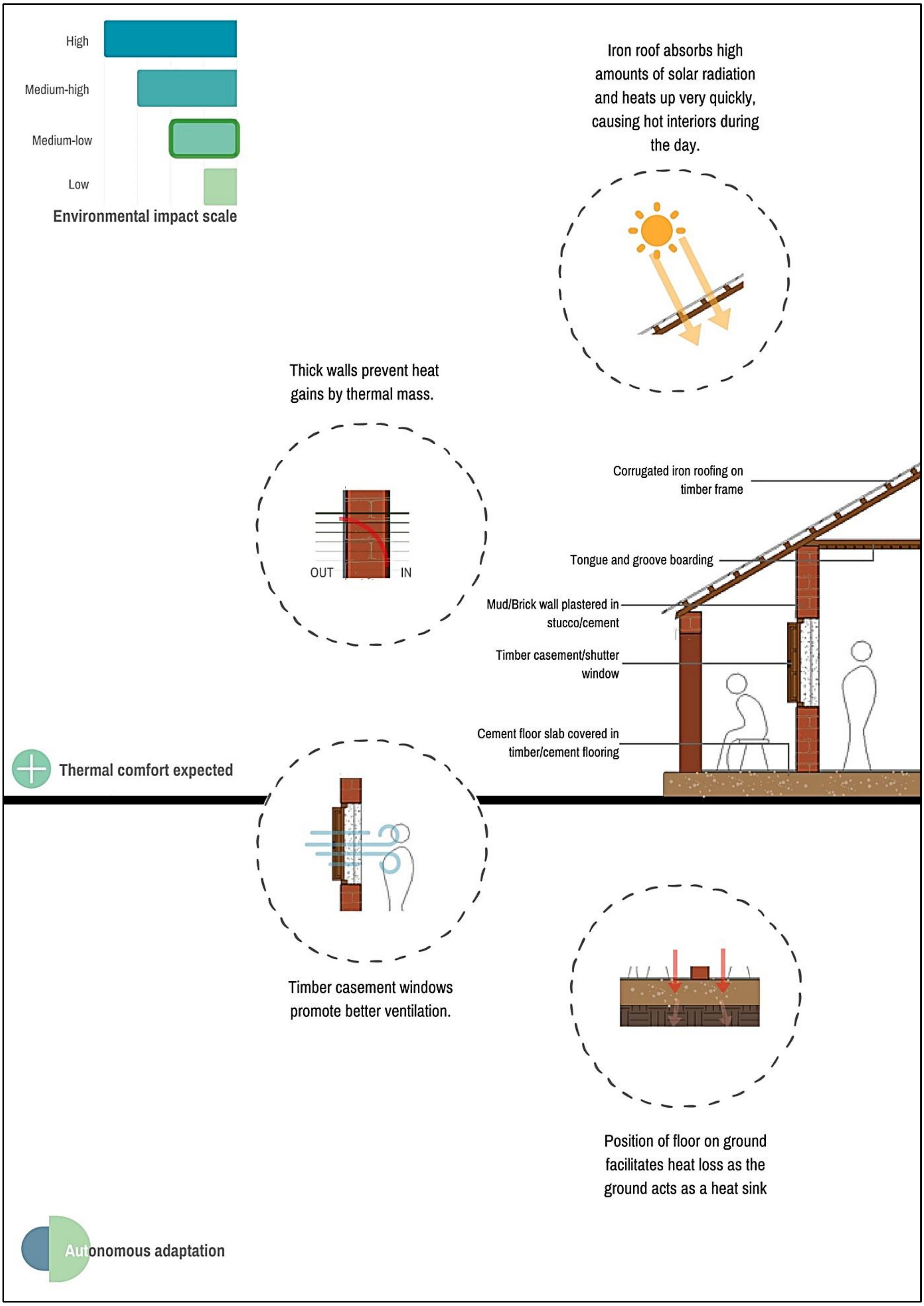


Figure 4.105 Section through Brazilian vernacular house envelope showing climate-responsive features; source: author's study - section based on Akinsemoyin & Vaughan-Richards (1977).

thermal comfort in the vernacular and contemporary house-types in Ibadan. Amongst all the houses, the indoor temperatures showed the least variation within the Brazilian house. The Brazilian envelope appears generally well-suited to the south-west Nigerian climate (see Figure 4.105); this may be explained by the origins of this architecture in a tropical environment (Brazil) and a sub-tropical environment (Portugal) (CIA, 2018a; CIA, 2018b). Both locations experience hot weather which influenced the architecture. Even in these foreign places, the climate-responsiveness of their architecture was refined over time (autonomous adaptation) (Fernandes, et al, 2015). Thus, it appears that these responses were more intrinsic than conscious; consequently, the south-west Nigerian Brazilian house envelope demonstrates an autonomous adaptation (see Figure 4.105). Generally, the materials used for the vernacular building envelopes have low-medium embodied energy, with minimal to moderate impact on the environment (see Table 4.1). Cement and iron pose substantial impact to the environment and the extraction of iron causes a large reduction in natural resources (Bribian, Capilla & Uson, 2011). As such these materials increase the impact of the envelope.

The earliest semi-modern European house envelope commonly featured walls built of timber or bamboo poles tied together, thatch roof and timber or mud flooring, occasionally raised on stilts. Differently, the later missionary houses showed similar construction of timber walls, windows, floors and corrugated iron roofs. This suggests a lightweight building envelope that was different from the solid envelopes of the traditional and vernacular types. In Chapter 2, a lightweight (timber) envelope was termed best-suited to the tropical climate because timber has low thermal mass and conductivity which ensures it does not store heat; rather it heats up and cools down very quickly. However, in tropical south-west Nigeria, the sun is directly overhead for at least 12 hours of the day (see next chapter). Therefore, it appears that the interiors will be heated up by intense solar radiation for most of the day. Night internal temperatures are expected to be cool and comfortable but the wide variations in temperature levels have been reported to be detrimental to thermal comfort (Reardon & Downton, 2013). Moreover, the elevation of the timber frames is advantageous to cooling as ground level obstacles to wind flow are avoided. However, the absorption of heat through corrugated iron roofs, seems to indicate more heat transfer to the interiors which is detrimental to thermal comfort. heat losses through the floor might be overidden as timber does not absorb heat readily. Differently, for thatch, heat absorption through the roof is minimised. According to Akinsemoyin & Vaughan-Richards (1977), the interiors of the semi-modern timber types were perceived as dark, gloomy and uncomfortable. However, authors such as Szokolay (1980; 2014), O'Brien (2006) and Lin (2004) propose lightweight construction as the most climate-responsive option for a tropical environment. Therefore, these authors state that timber construction indicates better chances for ventilation and cooling needed in the hot-humid south-west Nigerian climate. Yet this study proposes that

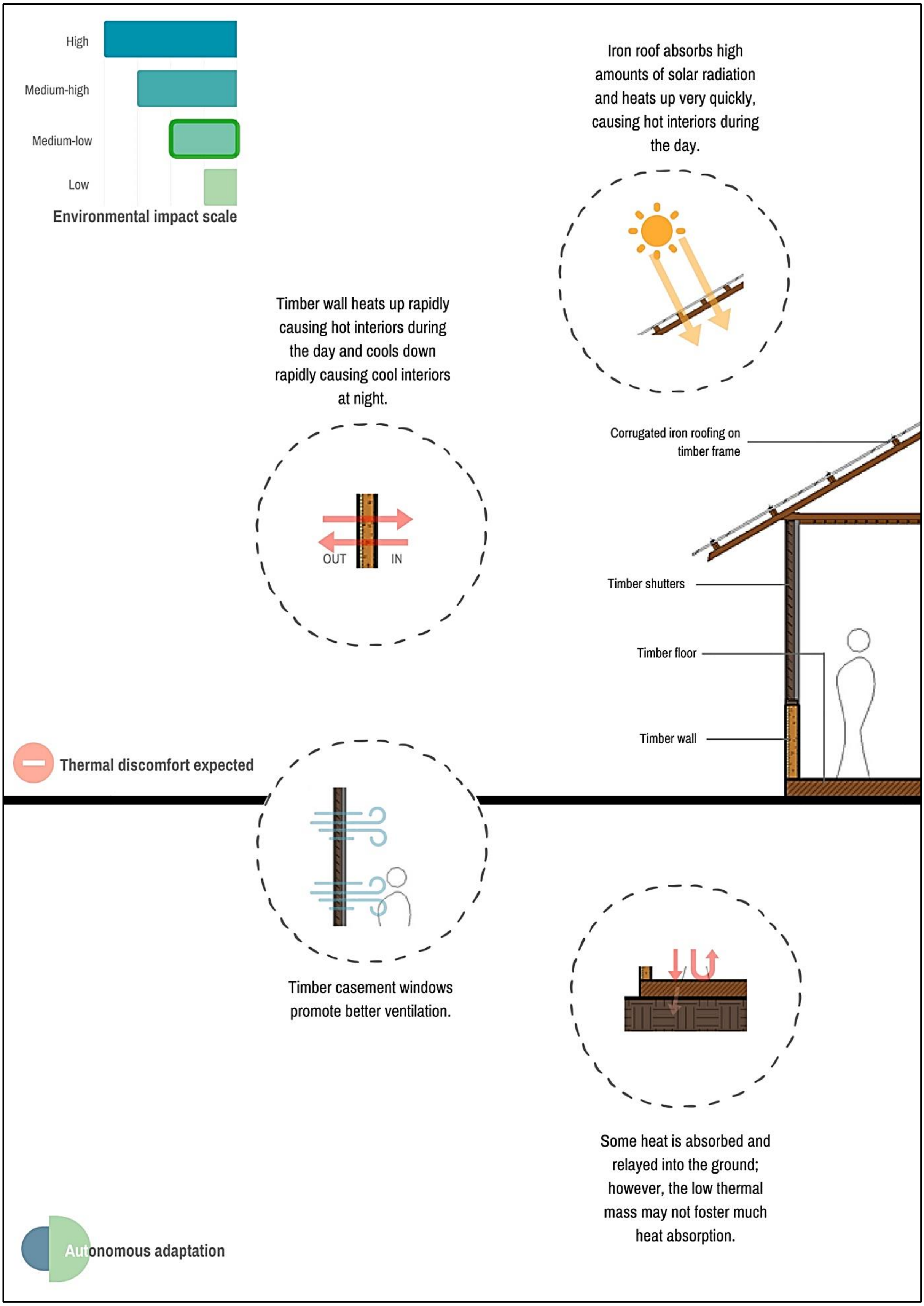


Figure 4.106 Section through semi-modern house envelope showing climate-responsive features; source: author's study - section based on Akinsemoyin & Vaughan-Richards (1977).

thermal discomfort would have been experienced for most of the day, because the lightweight timber frame would not have absorbed any heat by thermal mass and would have heated up quickly (see Figure 4.106). As such, this study agrees with Akinsemoyin & Vaughan-Richards' (1977) report of thermal discomfort. Nevertheless, this study asserts that there was no conscious consideration of climate-responsiveness in the semi-modern envelopes as it appears the British had not acquired a thorough understanding of the south-west Nigerian climate. Thus, the climatic adaptation of the semi-modern envelope seems autonomous as well because it was an unplanned and urgent response to the immediate need for housing (see Figure 4.106). However, the thermal outcomes of this adaption appear less positive than with the traditional and vernacular envelopes. This seems so because these solutions were not developed over time in the south-west Nigerian climate like the traditional envelope or a similar tropical environment like the vernacular envelopes. Furthermore, the materials used for the semi-modern building envelopes have low-medium embodied energy with a cumulative minimal to moderate impact on the environment (see Table 4.1).

More conscious climate-responsive design tailored towards the south-west Nigerian context, is obvious with the modern house-types. The principles employed here tally with the tropical design guidelines in Chapter 2 (see Figures 4.107 - 4.108). The establishment of the PWD brought in architects who were more aware of the designing for the tropics. These architects were able to build houses tailored to south-west Nigerian climatic contexts. Although the PWD housing was initially built to serve Europeans, more effort was put into understanding the south-west Nigerian climate. The earlier (1920s to 1930s) PWD house envelope commonly consisted of a mix of timber and stone/brick wall and concrete slab floor framing raised on reinforced concrete or timber stilts; large timber shutter windows with mosquito proofing; corrugated iron roof with extended eaves. The walls indicate thermal mass which helps to keep the interiors cool; cooling would have been aided by ventilation through the large timber shutter windows. Despite heat gains through the roof, the extended eaves shade the walls and windows, reducing the amount of solar radiation absorbed. The elevation of the building frame facilitates cooling as ground-level obstructions to wind flow are avoided. The high thermal mass of the floor indicates that some internal heat would have been absorbed by the floor and radiated into the space beneath. The later PWD envelopes formed the basis for other modern government housing schemes such as the LEDB low-cost housing. The common construction included cement/concrete walls and floors, glass windows and metal roofs. Conversely, the tropical modernist house envelope comprised of reinforced concrete beams, columns and floors supporting concrete block walls with glass paned windows, timber-framed roofs covered in asbestos tiles or aluminium sheets. While the walls for the both modern types indicate good insulation against heat by capacitive insulation (by the thermal mass principle), substantial heat gains are expected

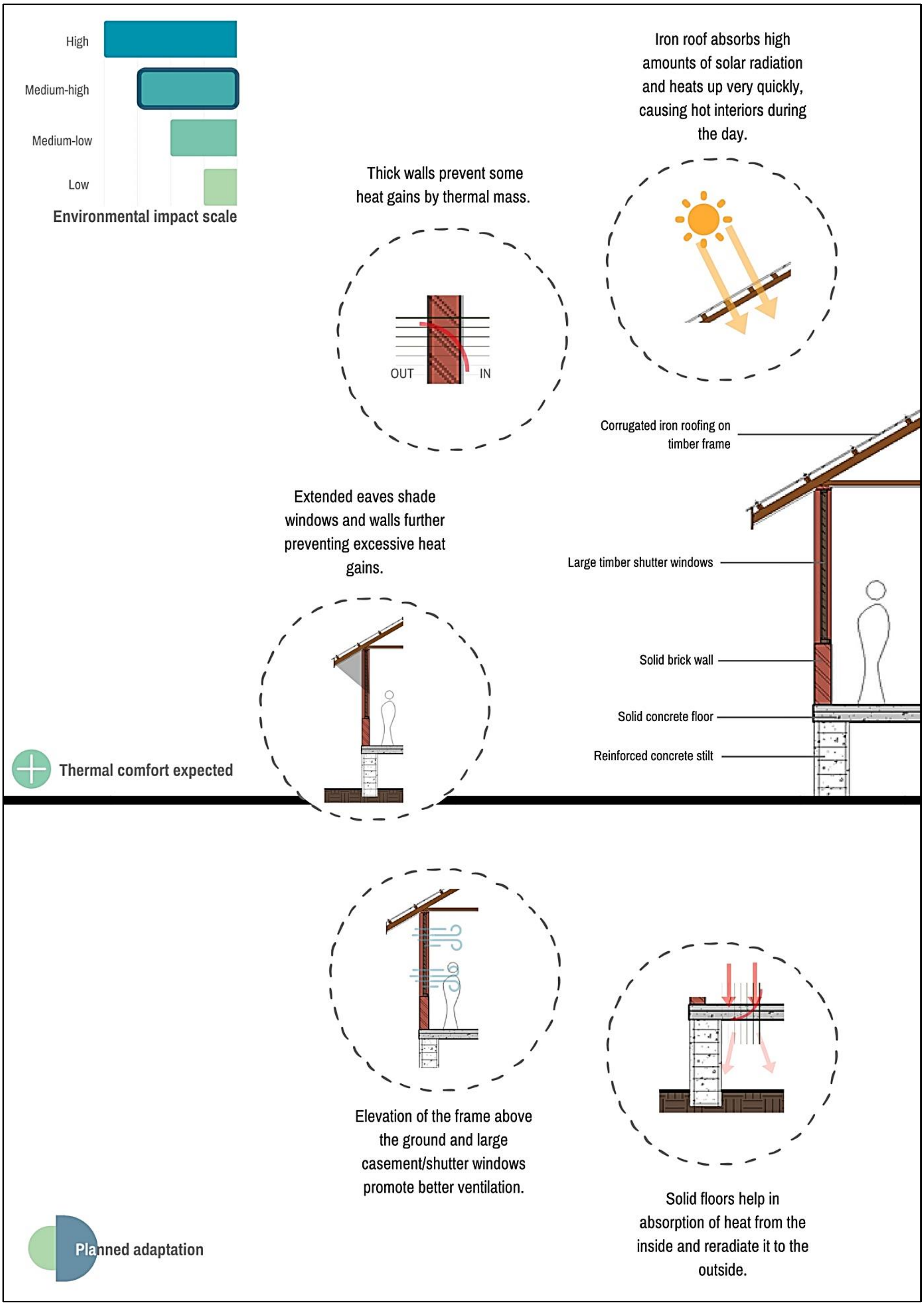


Figure 4.107 Section through modern PWD house envelope showing climate-responsive features; source: author's study - section based on Mabogunje (1962).

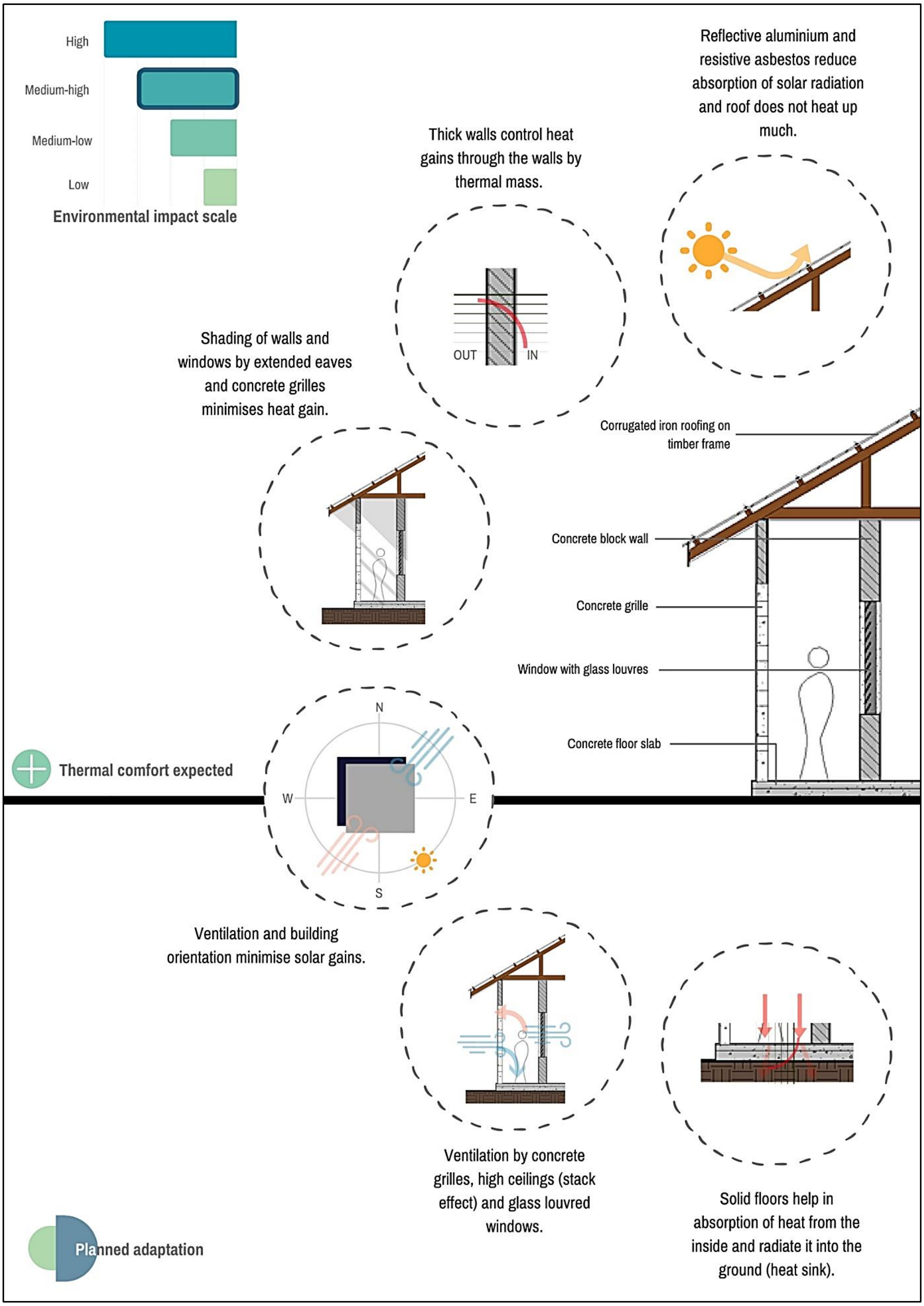


Figure 4.108 Section through modern PWD house envelope showing climate-responsive features; source: author's study - section based on Mabogunje (1962).

through the glass windows and metal roofs of the later PWD envelopes. Differently, the louvred windows of the tropical modern types suggest better ventilation which could have cancelled out the higher temperatures caused by absorbed solar radiation when the louvres were glass. Screen walls contributed to ventilation. The most common roofing coverings of aluminium and asbestos are attributed with a good thermal performance. Aluminium has good reflective properties while asbestos has good resistive insulating properties. Moreover, other climatic design principles were considered in the design of the tropical modern houses to ensure optimal thermal performance of the building envelope (see Figure 4.108). Building orientation was a primary consideration and the houses were sited to take advantage of the prevailing winds and minimise solar gains. Furthermore, there appears to be more flexibility with the distance of the ground floor above the natural ground level. For example, images of Fry and Drew's staff houses at UCI show different ground floor elevation distances above the natural ground level (see Figures 4.69 and 4.70).

The *Nouveau Rich* elite house envelopes were composed of concrete/reinforced concrete frame, cement/concrete block walls, glass windows and asbestos/aluminium roofing or flat concrete slab roofs. These are modern fabric features which have already been linked to qualitative climatic design principles (see Figure 4.108). Nevertheless, a new feature is the flat roof. In Chapter 2, well-ventilated roof spaces are recommended for hot-humid environs; this suggests a preference for pitched roof structures. However, if the flat roof did not perform optimally, it seems that other climatic design principles would have compensated for this. Ventilation and cooling are encouraged through the stack effect (facilitated by high ceilings) and taking advantage of breezes (by elevating the structure). Accordingly, the climate-responsiveness of the formal modern types indicates a conscious effort towards designing for the climate. This study offers that an acceptable level of thermal comfort was achieved in the formal modern envelopes as the implementation of climatic design principles was quite strong. The formal modern south-west Nigerian envelope presents as a model for planned adaptation as its climate-responsive features are based on careful, systematic and scientific considerations of the contextual climate. Considering the environmental impact of modern materials, the popular use of aluminium, steel and cement contribute greatly to the embodied energy of modern envelopes (see Table 4.1). Relative to previous building envelopes, more primary energy demand is needed for their production and more CO_2 emissions are released during production. Therefore, the modern building materials may be said to have a medium-high impact on the environment.

At the other extreme of the socio-economic spectrum are the informal settlements. The types of building envelopes identified in these settlements are very varied; however, some types bear similarities to previous building envelopes analysed in this section. The first type, cement-plastered mud walls, timber

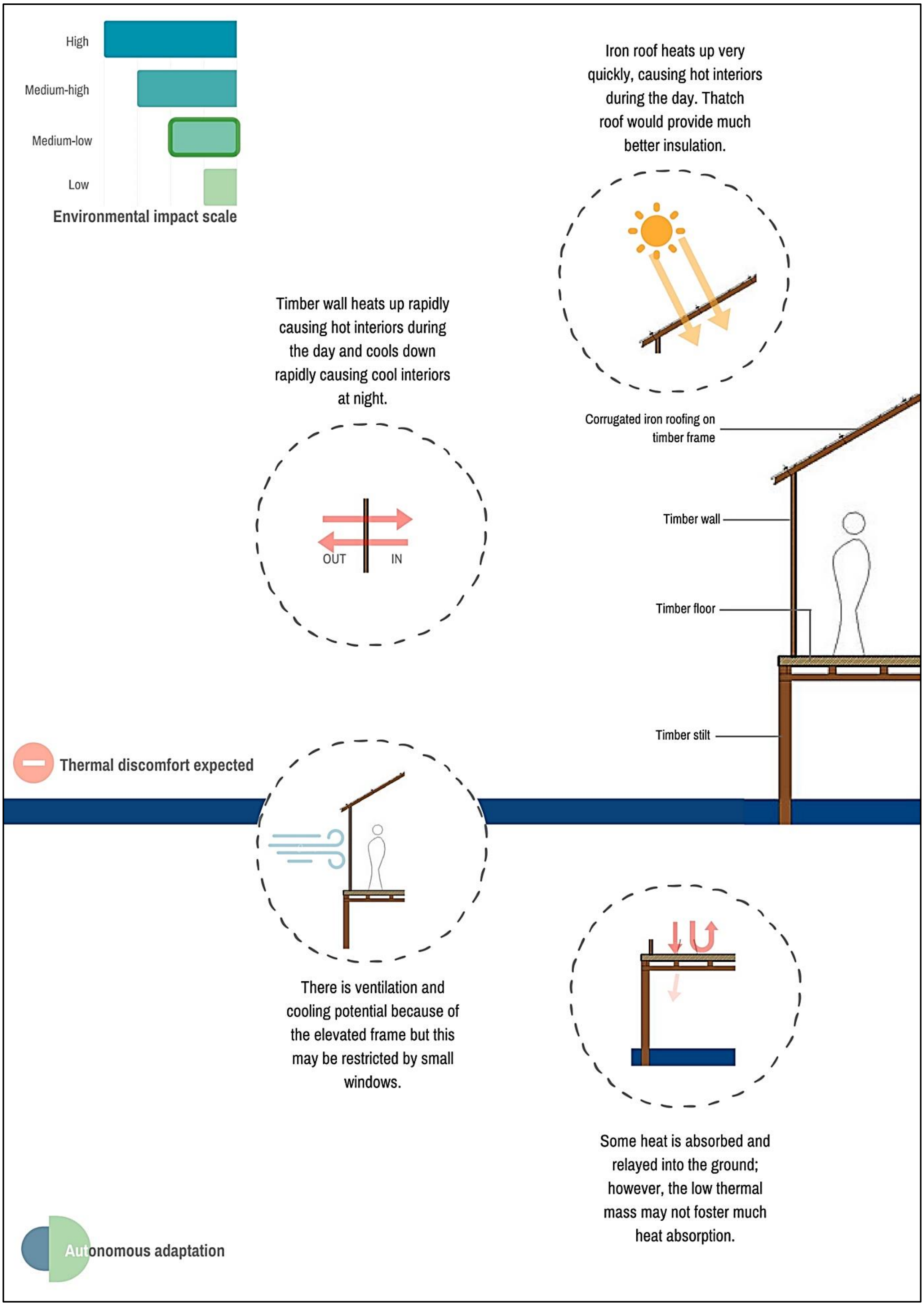


Figure 4.109 Section through the second identified informal settlement house envelope showing climate-responsive features; source: author's study - section based on Etomi (2011).

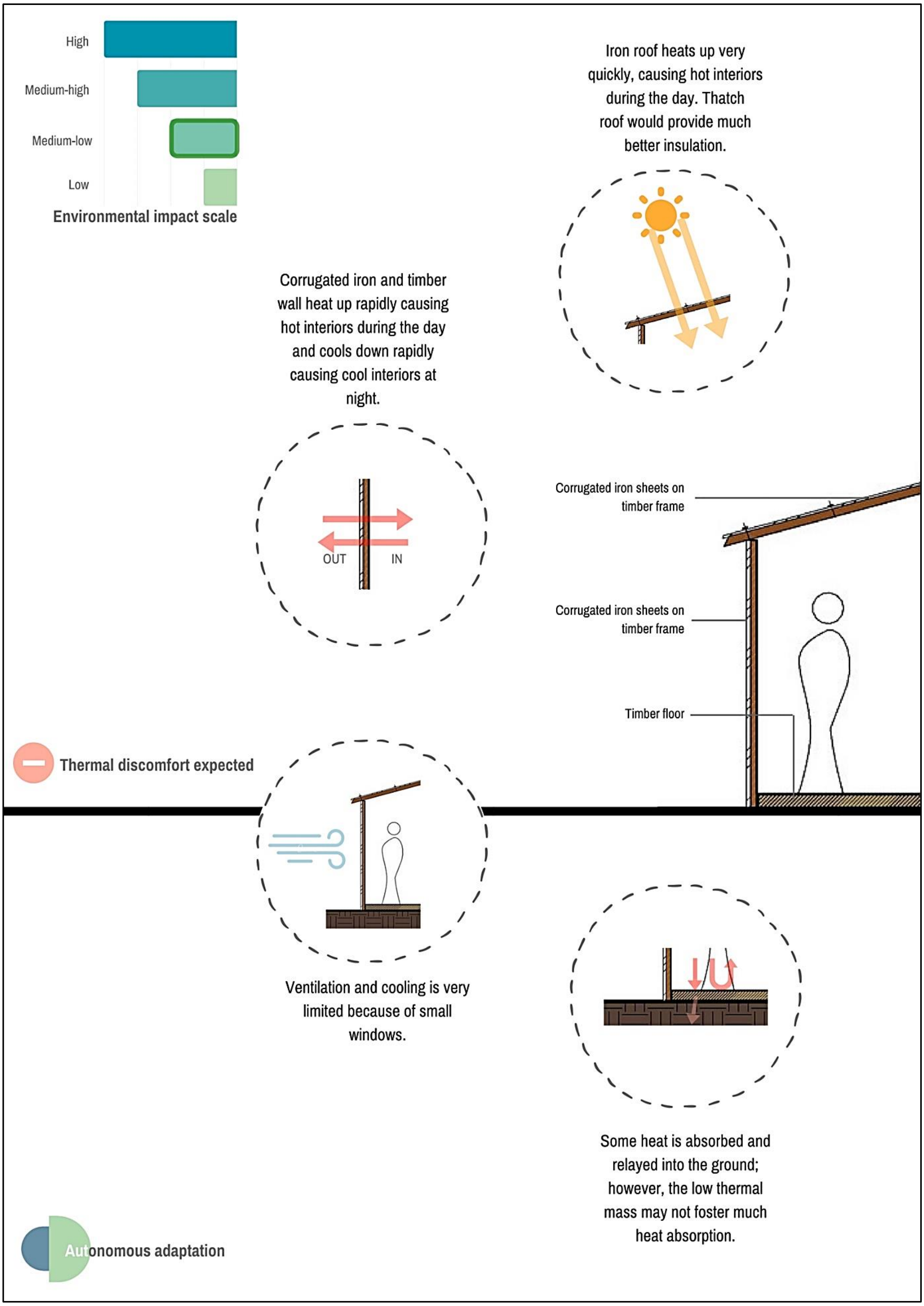


Figure 4.110 Section through the third identified informal settlement house envelope showing climate-responsive features; source: author's study - section based on Agbola & Agunbiade (2009).

roof trusses covered in corrugated iron sheets, is similar to the indigenous vernacular house envelope and its climatic design features are akin to the latter (see Figure 4.104). In cases where the wall is made of cement block, the wall displays thermal mass functions. The second type, timber walls (made of wooden planks or bamboo), small timber casement windows and roof covered in corrugated iron sheets or thatch (sometimes raised on stilts), has climate-responsive features comparable to the semi-modern types (see Figure 4.109). However, the small size of the windows may restrict ventilation and cooling potentials. The third type of house fabric, corrugated iron walls and roofs, seems a questionable envelope composition as iron admits large amounts of heat (see Figure 4.110). The potential here is a very hot interior for most of the day. In contrast, the informal settlements show no conscious efforts in this regard. Despite the variety among the informal house envelopes, the first type is akin to the indigenous vernacular house' therefore, it bears a similar low-medium impact on the environment (see Figures 4.109 and 4.110). Furthermore, the informal modern envelopes offer autonomous adaptation within the context similar to the semi-modern house envelopes: a spontaneous provision of housing. The other types feature the use of timber, thatch and iron; cumulatively, these envelopes pose a low-medium impact on the environment (Bribian, Capilla & Uson, 2011).

As stated earlier, the post-independence or contemporary house envelopes are not much different from the modern ones. The typical contemporary building envelope may be said to consist of reinforced concrete structural framing, concrete block wall panels plastered in cement; aluminium framed glass windows (sliding or casement); aluminium or zinc roofing sheets on timber roof trusses. However, contemporary house types feature smaller windows than formal modern types. This indicates less chance of ventilation through the windows and the glass panes are prone to heat gains. As with tropical modern envelopes, there seems to be increased flexibility with the distance of elevation of the ground floor level above the ground (Sheet 4.23 and Figure 4.99 show different contemporary envelopes with ground floors at different distances above the ground). Additionally, less importance has been placed on building orientation (see Sheets 4.1, 4.2, 4.10, 4.11, 4.18 and 4.19, where north-sign is omitted from professional drawings). Therefore, shading design is understated or absent and the potential for solar gains are increased. Nevertheless, solar gains through the roofs are reduced because the reflective aluminium roof cover, and concrete walls indicate some thermal control by thermal mass. Yet, there appears to be more reasons for heat gains (smaller glass windows, minimised shading design) through the envelope. Based on this lack of passive design principles, this study agrees with studies such as Denyer (1978) and Adunola (2014) that thermal discomfort exists within the contemporary house (see Figure 4.111). Denyer (1978) implied that modern construction in tropical cities poses thermal disadvantages when compared with traditional construction. Adunola's (2014) study is more specific as it reports thermal discomfort in

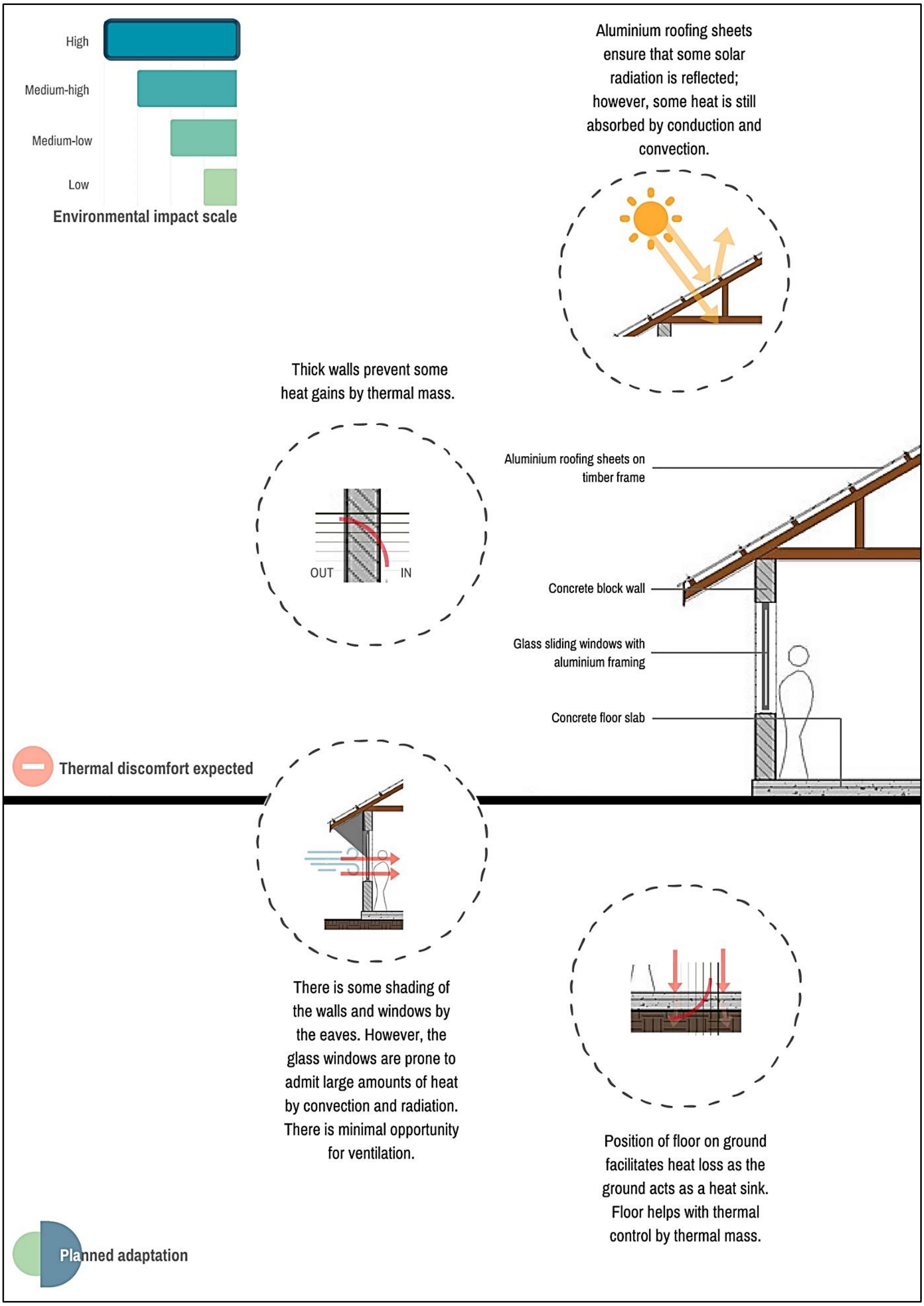


Figure 4.111 Section through the contemporary house envelope showing climate-responsive features; source: author's study - section based on professional architectural drawings represented in sheets.

most contemporary buildings in the south-west Nigerian city of Ibadan. This is in line with Lawal & Ojo's (2011) study where they discovered the hottest day-time temperatures in a contemporary concrete framed house. Accordingly, there is a strong dependence on mechanical cooling devices or active thermal controls to supplement the lapses of the building fabric. This corresponds with Short's (2017, p.4) statement that '…*the aggressive marketing of artificial weather released the design of buildings from any need at all to be responsive to climate*…'. The environmental impact of the contemporary building envelope may be classed as medium-high as some of its constituent materials (aluminium, steel, glass) have a high primary energy demand and global warming potential (see Table 4.1). Furthermore, electricity powers the mechanical cooling in contemporary house-types and Chapter 3 explains that the most reliable source of electricity is the generating set. As the national grid is an unreliable source of electricity, generating sets are commonplace, contributing to climate change in the region (RUWES, 2015; Ezema, Opoko & Oluwatayo, 2016). Thus, the mechanical augmentation of the building envelope increases the impact through substantial GHG emissions. Accordingly, the mechanically-supported contemporary house envelope poses the highest impact on the environment as it has the highest potential to aggravate global warming and climate change (see Figure 4.111). Nevertheless, the incorporation of the mechanical controls seems to be a form of planned adaptation to the climate, an adaptation that compensates for the indoor thermal discomfort created by architectural aesthetics.

It seems that there are varying degrees of climate-responsiveness across the south-west Nigerian house envelopes. In terms of climate adaptive features, the most positive form of climate-responsiveness may be seen with the traditional building envelopes and planned modern building envelopes. However, the traditional envelope outshines the formal modern envelope because the former has low global warming potential. Differently, the contemporary building envelope appears to possess the least positive form of climate-responsiveness especially due to the presence of mechanical cooling systems. The other types: vernacular, semi-modern and informal modern seem to sit between these two extremes. In terms of potential to exacerbate climate change, the traditional envelope has the lowest potential, while the contemporary envelope has the highest potential. The other types remain within the two extremes. Furthermore, two types of adaptation potential to climate have been highlighted among the south-west Nigerian house envelopes. The traditional, vernacular, semi-modern and informal modern envelopes offer autonomous adaptative principles. However, the most successful autonomous adaptation seems evident in the traditional envelope where indigenous south-west Nigerians developed their own architecture in response to their own climate. Planned adaptation is observed with the formal modern and contemporary envelopes; the modern envelopes show the more successful adaptation to the contextual climate. In Chapter 3, planned climatic adaptation, supplemented with lessons from autonomous climatic adaptation, is recommended considering climate change. This implies that the planned adaptive principles of the formal modern envelope need to be applied with input from the autonomous traditional adaptive envelope design. Still, considering the historical changes, all the house envelopes, apart from the original traditional types, may be identified in the contemporary south-west Nigerian society. This indicates that there are different preferences of housing dictated by other factors. Therefore, the question of the most culturally relevant domestic envelope in contemporary south-west Nigerian society needs to be answered.

4.5.1 Determining what south-west Nigerian building envelope is relevant for climate-change adaptation in contemporary south-west Nigerian society and climate

The studies of Oyedele (2016) and Okeyinka & Amole (2012) suggest that there are two aspects of south-west Nigerian housing which form the bases for societal house-type preferences in the region. Oyedele's (2016) study proposes that modern/contemporary construction has well-defined advantages over traditional construction; these advantages are centred around technological innovations and structural integrity. Okeyinka & Amole (2012) report that south-west Nigerians tend to prefer house-types based on functionality, emotional comfort and privacy. Therefore, in determining the most relevant contemporary south-west Nigerian house-type in developing a climate-responsive and adaptable house envelope, this study will attempt to:

- investigate the most preferred construction in contemporary south-west Nigeria;
- ascertain the socio-culturally preferred house-type and accompanying style in contemporary south-west Nigeria,

based on existing literature. Considering the structural composition of the south-west Nigerian domestic envelopes, this study has highlighted three categories:

1. traditional construction: timber, thatch and earth;
2. transitional construction (for vernacular, semi-modern and informal modern envelopes): cement, earth, timber, iron, stucco;
3. contemporary construction (for formal modern and contemporary envelopes): concrete, reinforced concrete, steel, aluminium, zinc, asbestos, glass, timber.

When considering the structure of the traditional house envelope, previous research highlights the positives of traditional construction. As described earlier, the local availability of the materials portrays a cost-effective option. Some authors such as Fourchard (2003) and Adeokun (2013) suggest a positive assessment of the durability of traditional construction as they report that large portions of indigenous structures still survive today. Furthermore, Dmochowski (1990) points out that the pillars of the Abeokuta *afin* were spaced at 2m centre to centre, a standard length for a timber beam between supports. This seems to indicate that the Yoruba traditional architects had a robust understanding of building structures. It is insinuated that the strength of traditional construction can last years if properly maintained (Lloyd, Mabogunje & Awe, 1967; Denyer, 1978). However, this maintenance has been described as a difficult and time-consuming process (National Park Service, 1978; Standiford, 2014). For example, adobe-based mixes must be used in retouching a mud wall; this is a time-consuming and difficult process. Mabogunje (1962) mentions that the one-storey houses in the oldest parts of Ibadan were made of poor sun-baked or kiln-dried mud bricks which could easily be washed away by the frequent floods of the area. Consequently, mud has been prohibited as a construction material for buildings in south-west Nigeria (N-AERUS, 2001). Adenle (1967) assessed the structural conditions of remnant traditional house-types in Iwo and judged the structural condition as poor. Onyegiri & Ugochukwu (2016) list low strength/durability and frequent maintenance as one of the several challenges of traditional construction. The historical description of the house-types show that the thatch roofs of the traditional types were found to be highly flammable and gradually replaced with corrugated iron sheets. This indicates that the structural integrity of traditional construction is questionable.

Generally, the structural integrity of transitional construction seems to have an edge over that of traditional construction (Ibid). Previously, the brick construction of the Brazilian types was referred to as sturdy or solid (Lloyd, Mabogunje & Awe, 1967). Thus, the construction afforded multi-storey buildings, making them a facilitator of multi-storey house construction in the region (Vlach, 1984). These types remain in present-day south-west Nigerian cities; however, earlier on, it was stated that the construction has deteriorated over time due to inadequate maintenance. The structural integrity of the indigenous vernacular construction appear to be largely akin to that of the traditional construction. Nevertheless, the modifications, corrugated iron sheets in place of thatch and cement-plaster for mud walls, present a slight strengthening of the indigenous vernacular construction. The semi-modern types predominantly featured timber framing which afforded multiple-floor construction. The first two-storey building in Nigeria was the 1842 mission house built in Badagry, Lagos (Oyediran, 2017). However, the structural integrity of timber is compromised because of its susceptibility to fungus and insects (Akinsemoyin & Vaughan-Richards, 1977). Hence, it appears that the excessive use of timber construction in the south-west Nigerian environment is inappropriate. Furthermore, timber frames are highly inflammable; fire outbreaks in the informal settlements have been reported (Simon, Adegoke & Adewale, 2013). Apart from this detriment of timber framing, the quality of other informal house construction has been described using terms such as ‘ramshackle’, ‘sub-standard’, ‘badly-built’ (Immerwhar, 2007; Ibid; Daniel et al, 2015). Therefore, in the case of transitional construction, it appears that although the structural benefits are more than that of traditional construction, issues with strength, maintenance and safety persist.

The structural integrity of formal modern construction has been praised for durability, technological innovation and ease of maintenance (Oyedele, 2016). The historical description of housing has shown that the PWD and tropical modern houses showed more sophisticated construction detailing than earlier south-west Nigerian types. The University of Ibadan residential buildings by Fry and Drew, then later by the Design Group demonstrate the structural versatility and innovation of modern construction. In his January 1945 letter to Drew, Fry mentions the benefits of modern architecture: functional integrity, neatness and economy. Furthermore, the earlier discussions show that many of the modern house-types still exist today, a compliment to the quality of modern construction. However, the main argument against modern construction is its high cost. Marris in his 1961 study on housing in Lagos, notes that due to modern housing estates' architectural style and hence costly building materials and construction, they could not be afforded by the target users: Lagos-based low-income earners. Consequently, the low-income earners resorted to informal housing solutions. Still, this criticism may be dispelled because many of these materials are now locally produced, thereby lowering their prices (Oyedele, 2016). Although issues of maintenance exist with contemporary construction, Oyedele (2016) suggests that modern materials are designed for better performance including less maintenance inputs. For example, modern painted walls are cheaply and conveniently maintained over long intervals using cans of paint (Standiford, 2014). Another criticism of modern construction is the use of materials that threaten health, the most prominent example being asbestos. Asbestos was introduced as an innovative material and possesses good resistive and insulating properties (Onyeaju, Osarolube, Chukwuocha, Ekuma & Omasheye, 2012). Therefore, it was popularly used in the 1950s to 1960s tropical modern construction as a roof covering. However, with furher research, asbestos has been identified as having carcinogenic effects, making it a health hazard (WHO, 2012; Kusiorowski, Zaremba, Piotrowski & Adamek, 2012). Although there is no ban against its use in construction in Nigeria, the information about its threat to health has spread. Consequently, its use in building construction has declined but not completely disappeared; hence, aluminium roofing sheets have become the most popular choice for contemporary roof covering (Ahmetovih, Qozih & Abdullahi, 2010; WHO, 2012).

Accordingly, there seems to have been a gradual selection and refinement of modern materials which has ensured their continued usage in contemporary construction. Thus, the components of contemporary construction are very similar to modern construction, bearing the same desirable qualities of structural integrity, durability and innovation. Reinforced concrete, concrete, glass and aluminium have endured into contemporary times. However, the historical description of housing development has shown that in contemporary times, contemporary construction is increasingly becoming popular as new builds continue to feature contemporary construction. Furthermore, the technological innovation in contemporary construction has led to the development of more sustainable contemporary materials with lower global warming potential and embodied energy (Oyedele, 2016). For example, the production and use of aluminium has been identified as having a high global warming potential (Bribian, Capilla & Uson, 2011). Therefore, researchers have recommended that the metal can be reused using the recycling process which greatly reduces its global warming potential (Hutchinson, 2008; Efthymiou, Cöcen & Ermolli, 2010). Moreover, the structural characteristics of the predominance of contemporary materials and construction, such as steel and glass windows and concrete walls, seems supported by the reports that they meet current socio-cultural needs for security and privacy (Akinluyi, Akingbohungbe & Ayoola, 2012).

According to Okeyinka & Amole (2012), these values are two of the three most-mentioned reasons why the contemporary bungalow is chosen as the contemporary representation of the family house or ‘home’. This finding is supported by Chokor (2007) who adds that in a 1984 survey showed most people across all socio-economic classes in major Nigerian cities such as Ibadan, Lagos, Benin City, Kano and so on, favoured contemporary bungalows with three or more bedrooms. According to the survey by Okeyinka & Amole (2012), 40.25% of the 400 residents of a south-west Nigerian residential area (Oshogbo, Osun State), acknowledged the contemporary middle-class bungalow as ‘home’, among six contemporary house types. Okeyinka & Amole (2012) add that these are basic house types where slight variations abound due to the contemporary culture mix and the accompanied varied lifestyles and backgrounds. Individual preferences and variations in economic status are responsible for modifications to these basic house types. These modifications in the type and quality of façade embellishments, fittings and fixtures, the number of storeys and so on, create the illusion that the houses are of other configurations. Based on their detailed description of studied house-types, this study has matched five of the types from Okeyinka & Amole’s (2012) study to those it has identified: the family house (the indigenous vernacular house); the single house on one plot occupied by one family (the detached contemporary bungalow patterned after the PWD bungalow); the apartment building (the contemporary block of flats patterned after the PWD blocks of flats), the duplex (contemporary variant of the single detached bungalow); rooming house (the vernacular Afro-Brazilian rooming house). Table 4.2 shows the relative preferences of the respondents towards the various house-types.

Accordingly, Okeyinka & Amole’s (2012) study investigated attitudes towards the vernacular and contemporary house-types which exist currently in the region. In line with their findings and based on its own historical and cultural examination, this study suggests that there is an adversity towards the vernacular house-types for the following reasons. First, the vernacular houses are associated with low-income earners who do not possess the affluence and influence wealth gives in society. According to Lloyd, Mabogunje & Awe (1967, p.136), "…*the present elite…within twenty years if their own life-times, many have moved from the traditional compound of a poor farmer to a modern government or university house furnished in a manner appropriate to a four-figure salary*…" Therefore, it appears there is a social bias against vernacular houses based on a desire for progressive lifestyles displayed by the elite. This bias is demonstrated by the tendency of south-west Nigerian indigenes to update vernacular residences with contemporary materials, even though they remain in vernacular neighbourhoods, because of ties to ancestral land (Fourchard, 2003; Immerwahr, 2007). Secondly, the vernacular houses are located in the oldest parts of south-west Nigerian cities and display the highest population density, lower quality of life and infrastructure than the contemporary residential areas. Earlier on, it was observed that these areas have been termed informal settlements based on the low standard of living and infrastructure. Therefore, the deteriorated quality of the housing and hence, neighbourhood leaves little to be desired amongst south-west Nigerian residents. The high population density of these areas promotes close social interactions and communal living which are directly opposite to the Western ideal of privacy. Furthermore, crime rates are higher in these areas due to the lack of structure and physical planning (Simon, Adegoke & Adewale, 2013; Daniel et al, 2015). Therefore, south-west Nigerians prefer the security afforded in contemporary neighbourhoods where the population is less, more educated and wealthier. Thus, it may be said that the contemporary bungalow is the most socio-culturally preferred house-type in contemporary south-west Nigeria.

Table 4.2 Table showing the frequency distribution of house-types that south-west Nigerians readily think of as home in current times.

Original term from Okeyinka & Amole (2012)	Author's corresponding term	Frequency	Percentage (%)
Family house	Indigenous vernacular house	50	12.5
Single house on one lot occupied by one family	Contemporary bungalow	161	40.25
Apartment in a building with more than one apartment	Block of flats	70	17.25
Duplex	Contemporary variant of bungalow	91	22.75
Rooming house or 'Face-me-I-face-you'	Brazilian vernacular rooming house-type	21	5.25
Others	-	07	1.75
Total	-	400	100

Source: adapted from Okeyinka & Amole (2012)

Considering the above discussions, this study suggests that contemporary construction and bungalow are the most preferred by south-west Nigerian residents. It has been observed that contemporary construction has advantages over transitional and traditional construction because it:

1. features the least negatives with integrity, durability, occupant health and maintenance;
2. is increasingly becoming affordable because of the growing popularity of contemporary house-types;
3. permits the most innovation regarding structural durability and sustainable construction solutions.

The choice for contemporary construction is supported by the socio-cultural preference for the contemporary bungalow based on security and privacy. This may be said to illustrate the acceptance of the individualistic Western lifestyle by south-west Nigerians mentioned earlier. Considering the analysis of climate-responsiveness and adaptation potentials of the south-west Nigerian envelopes, it was observed that the traditional house envelope offers the most successful climate-responsive features through autonomous adaptation. Additionally, traditional construction seems to pose the least threat to the environment. However, when considering the preferred construction and house-types in present south-west Nigeria, there appears to be an adversity towards the traditional house-type and construction. On the other hand, the formal modern house envelope shows successful climate-responsiveness through planned adaptation. Yet, this study presents that the contemporary house-type seems to be more preferred to modern house-types. Based on the discussions so far, it seems that the contemporary house envelope evolved from the modern house envelope. The difference between both is that the passive thermal controls of the modern envelope have been substituted with active mechanical thermal controls. This study has identified the inclusion of mechanical thermal controls in the contemporary envelope as a negative form of planned adaptation. Via mechanical controls, global warming potential is raised in the contemporary house envelope. Therefore, this study proposes that the contemporary bungalow envelope is most relevant in addressing climate change in south-west Nigeria. The contemporary bungalow envelope can be optimised to achieve climate-responsiveness:

1. through planned adaptation - learning from the successful application of passive climatic design principles through a planned adaptation approach as seen in the modern envelope; exploring innovative contemporary construction solutions (envelope assemblies) and their effects on the thermal performance of the contemporary house envelope;
2. learning from autonomous adaptation – examining the effect of incorporating passive climate-responsive features of the traditional house envelope in the contemporary house envelope, on the latter’s thermal performance.

These will be achieved using quantitative methods of thermal analyses of the envelope performance for the contemporary and traditional types, and a parametric optimisation of the contemporary envelope according to passive climatic design principles for tropical climates. As such, this study intends to demonstrate Short's (2017) statement that a recovery of naturally controlled environments with no reliance on artificial or mechanical thermal controls, is possible. This recovery will ensure that contemporary housing is resilient to climate change featuring the minimum use of energy. It proposes to do this in the context of south-west Nigeria. However, is this proposal indeed significant when considering climate change adaptation and housing in south-west Nigeria?

4.5.2 The relevance of an optimised climate-responsive contemporary domestic envelope to climate change adaptation in south-west Nigeria

Although this study's proposal seems like one of very many which fall within the broader climate-change adaptation context, it attempts to fill larger context-specific gaps in the south-west Nigerian climate change and adaptation. Studies directed specifically at climate change adaptation via the physical aspects of south-west Nigerian housing seem to be lacking. However, Adedokun (2014b) refers to the climate-responsiveness of the traditional house-types. Adedokun (2014b) explains that the materials, roof design and courtyard space can be included into modern south-west Nigerian housing to produce current domestic architecture sensitive to climate. This implies that the climate-responsiveness of the traditional house has been identified as useful in the contemporary housing context. However, it remains at prescription stage; there appears to be no further research to investigate the feasibility of this idea. Additionally, Adedokun (2014b) refers to this idea in the present climatic contexts; there is no obvious allusion to adaptable south-west Nigerian housing in future climates. However, Adedokun (2014b) admits that, in lieu of climate change, the benefits of exploring current and future climate-responsive housing solutions are vast. Peter & Adewale (2015) identify the implications of global warming on thermal comfort in buildings in southern Nigeria. Their study seems to be one of the few that acknowledge climate change and its effects on thermal comfort in southern Nigeria. With the predicted increases in temperature, Peter & Adewale (2015) express concern that the cooling potential of natural ventilation will be reduced. They propose that the western influences in the contemporary architecture of the region must be reduced to cultivate climate-specific responses which are expected to ensure adaptability.

Furthermore, they prescribe general principles on how building design can adapt to climate change in aspects: layout and form, roof design and materials, landscape, shading, fences and walls, and material specification. Most of these principles are based on the climatic design guidelines outlined in Chapter 2.

One of such prescriptions involves the debate about the suitability of heavyweight or lightweight materials in the south-west Nigerian climates. However, that is all these principles are, prescriptions without proof, which indicates a need to probe if and how these prescriptions are appropriate in developing contemporary climate-responsiveness and adaptation. Then, it seems necessary to take this one step further by investigating the feasibility of climatic design prescriptions for a contemporary south-west Nigerian residential building envelope in changing south-west Nigerian climates. Furthermore, it appears there is a research thread stating that even if contemporary buildings are developed with passive thermal controls, they must be augmented by active controls. In Chapter 2, this study mentions Szokolay's (1980) stance that a new approach to passive design for the tropics would be the design of a contemporary envelope functioning with passive climatic principles but supported by active thermal controls. However, this study has shown that the presence of active thermal controls seems to do more harm than good to the already-problematic tropical climate. The desired result is to produce a contemporary house envelope which promotes optimum thermal comfort, reducing reliance on high carbon solutions and hence, adapting to and mitigating climate change. Amidst numerous qualitative studies on climate responsiveness in south-west Nigerian traditional, vernacular and contemporary house types, Ezema, Opoko & Oluwatayo's (2016) quantitively research reducing carbon emissions in Nigerian residencies, as a form of climate change mitigation and adaptation. They approach the subject by working out the amount of carbon embedded in the production of a typical contemporary south-west Nigerian residence throughout its lifespan. They state that the standard lifespan of the contemporary house types is 50 years. They assert that the operational and embodied carbon in the house's entire life cycle must be kept to a minimum by employing low carbon energy development strategies. A distinct conclusion of their study is that carbon mitigation strategies should ideally be applied to energy consumption first.

Additionally, Ezema, Opoko & Oluwatayo's (2016) study reveals that most of the operational emissions came from the region's dominant reliance on electricity generated by processing fossil fuels. It has been stated that reliance on electricity is necessary for HVAC and other domestic systems in contemporary south-west Nigerian housing. Olaniyan, Ayinla & Odetoye (2013) recommend more research into the thermal analyses of common fabrics of the building envelopes in southern Nigeria, with little or no input from mechanical thermal control systems. Lawal & Ojo (2011) investigated the thermal comfort levels of vernacular house types in the south-west Nigerian city of Ibadan and concluded that adobe mud walls, cement-sand rendered floor and iron roof coverings are best for the contextual climate. However, they do not consider climate change adaptation and specify whether the models are dependent on HVAC systems. Therefore, with its proposal, this study aims to develope a contemporary house envelope, devoid of mechanical cooling systems and specific to the changing climate of the region. Furthermore, the successful climate-responsiveness in the traditional house-type have mostly been qualitatively analysed (Dmochowski, 1990; Prucnal-Ogunsote, 1993; Itajuyi & Taiwo, 2012; Adedokun, 2014b); this study has contributed to numerous qualitative assessments in attempting to identify climate-responsive and adaptation potential of the traditional house envelope. However, this study suggests that these assessments can be objectively tested through an objective inquiry into the thermal performance of the traditional house envelope. Based on this quantitative assessment, the features that might be useful in optimising the contemporary house envelope can be objectively identified.

Thus far, it seems apparent that this study's proposal may fill the following gaps in south-west Nigerian climate change adaptation through housing:

- Objective assessment of thermal performance of free-running traditional and contemporary envelopes;
- Determining if successful climate-responsive features of the traditional envelope can be incorporated into the contemporary envelope;
- The resilience of both envelopes' thermal performance to climate change;
- Investigations into the applicability of tropical climatic design principles in optimising the contemporary envelope.

In Chapter 2 and 3, thermal comfort was identified as the most common indicator of climate-responsiveness, climate-resilience and climate-adaptation in building envelope design. Hence, the assessment of thermal comfort within the traditional and contemporary envelopes will be used in determining climate-responsiveness and adaptation potentials. Accordingly, the main question this study remains: can a climate-resilient, climate-responsive and climate-adaptive contemporary SW Nigerian family house envelope be cultivated for now and the future? Furthermore, the following sub-questions need to be objectively answered:

1. Are the traditional and contemporary SW Nigerian family house envelopes climate-responsive, providing optimum thermal comfort in present and future climates?
2. Which provides better thermal comfort now and in the future, between the traditional and contemporary family house envelopes?
3. What design principles (within the context of climate responsiveness and adaptation in residential building envelope design) apply in the south-west Nigerian context?
4. How can a climate-resilient and adaptive contemporary SW Nigerian family house envelope template, promoting optimum thermal comfort now and in the future, be developed?

5. Are there features of the traditional house envelope that can be borrowed and infused into the optimally performing building envelope?
6. Is the combination of planned and autonomous climate adaptation applicable in developing a climate-resilient and adaptive SW Nigerian family house envelope template, promoting optimum thermal comfort now and in the future?

Based on previous analyses, this study will select the models of traditional housing: the compound house and contemporary housing: the contemporary bungalow in answering these questions. The compound house has been chosen because it is the basic representation of south-west Nigerian housing. Secondly, its envelope has been argued as the most successful climate-responsive south-west Nigerian traditional house-type. Moreover, it demonstrates the autonomous climate adaptation approach which can be learned from. The contemporary bungalow appears as the typology most associated with popular contemporary family living within the social context of contemporary south-west Nigerian society. It has a low level of climate-responsiveness caused by a lack of the application of passive climatic design principles. Therefore, its planned adaptation to the south-west Nigerian climate is achieved through active thermal controls which aggravate climate change. This study intends to use the more successful planned adaptation achieved by using passive climatic design principles (as seen in formal modern house-types), in optimising the contemporary house envelope. This approach will be supplemented by learning from the autonomous adaptation of the traditional envelope. Therefore, the sample size is constrained to two house-types, which according to Kumar (2011), is a logical approach when dealing with similar elements within a study population. Accordingly, this study intends to investigate the thermal comfort conditions in free-running models of these types now and in the future.

4.6 Conclusion

This chapter has investigated the historical evolution of south-west Nigerian housing and its envelopes. It has identified different categories of South-west Nigerian housing due to socio-cultural changes. These categories are traditional, transitional (vernacular and semi-modern), modern and contemporary. In this way, this study has discussed the socio-cultural meanings of traditional and contemporary housing, thereby meeting this study's first objective. The building envelopes across these categories have been qualitatively analysed considering climate-responsiveness and climate adaptation approaches. This study states that the traditional envelope shows the highest degree of climate-responsiveness through an autonomous adaptation approach confirming the discussions of Chapter 3. On the other hand, the contemporary envelope shows the least degree of climate-responsiveness and planned adaptation to climate through mechanical controls with high global warming potentials. However, the south-west Nigerian formal modern house envelope demonstrates that planned adaptation to climate through passive climatic design principles, can be achieved without worsening climate change. This chapter has additionally shown that the middle-class contemporary bungalow is the most socio-culturally accepted house in the region. As such, this study proposes that the climate-responsiveness and adaptation of the contemporary house envelope may be optimised. It proposes this can be done by employing the climatic design principles applied in the modern house types through planned adaptation. The application of these principles can be augmented by learning from how they were demonstrated in the traditional envelope through autonomous adaptation. At this point this study is set to produce proven facts that can be applied as part of the effort towards climate change adaptation in south-west Nigerian housing. The next two chapters thoroughly explore the potential for climate-responsiveness and climate-adaptation of the traditional and contemporary south-west Nigerian house types for now and in the future.

References listed in the second volume